Agenda of $nn'$ Collaboration meeting September 18, 2026 at ORNL

| | | |
|---|---|---|
| 1. | Yuri Kamyshkov | Overview of finished measurements and data for nTMM-2 experiment |
| 2. | Alina Moore | Analysis of nTMM-1 2025 data |
| 3. | Carolyn Haviland | Analysis of nTMM-1 2025 data |
| 4. | Mubi Khan | Magnetic calculations for mu-prototype and more |
| 5. | Linus Persson | Magnetic field reconstruction in nTMM-2 |
| 6. | Evan Michael | Pressure gauge image recognition |
| 7. | Yuri Kamyshkov | Plans and projects for 2026 data analysis |
| 8. | Discussion on first PRL nTMM publication preparation | |
| 9. | Discussion of NIM publication for mu-prototype studies | |
| 10. | Yuri Kamyshkov 25’ | Measurements with mu prototype |

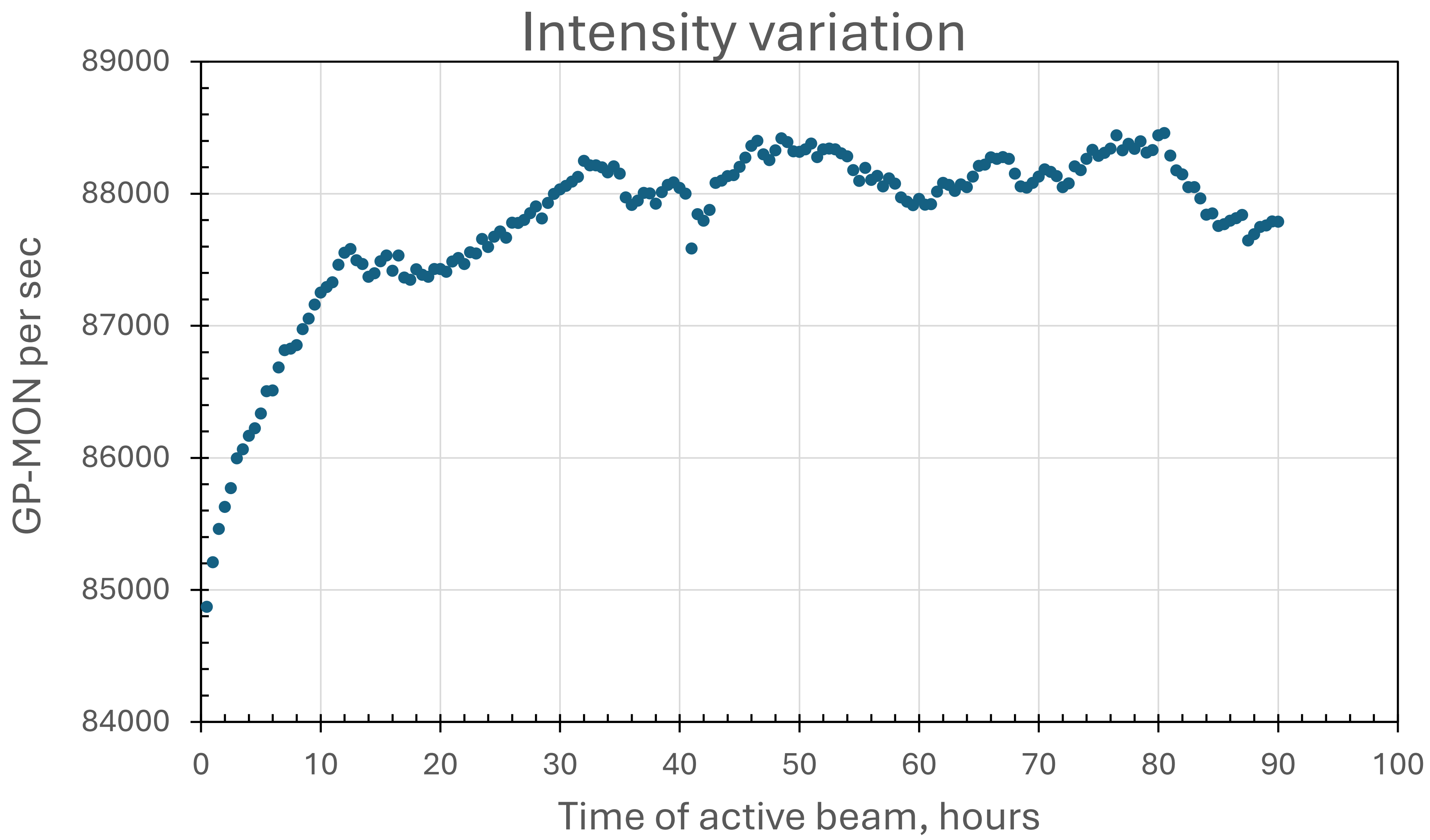
All speakers: please send your slides to kamyshkov@utk.edu for INDICO posting

# Overview of finished measurements and data for nTMM-2 experiment

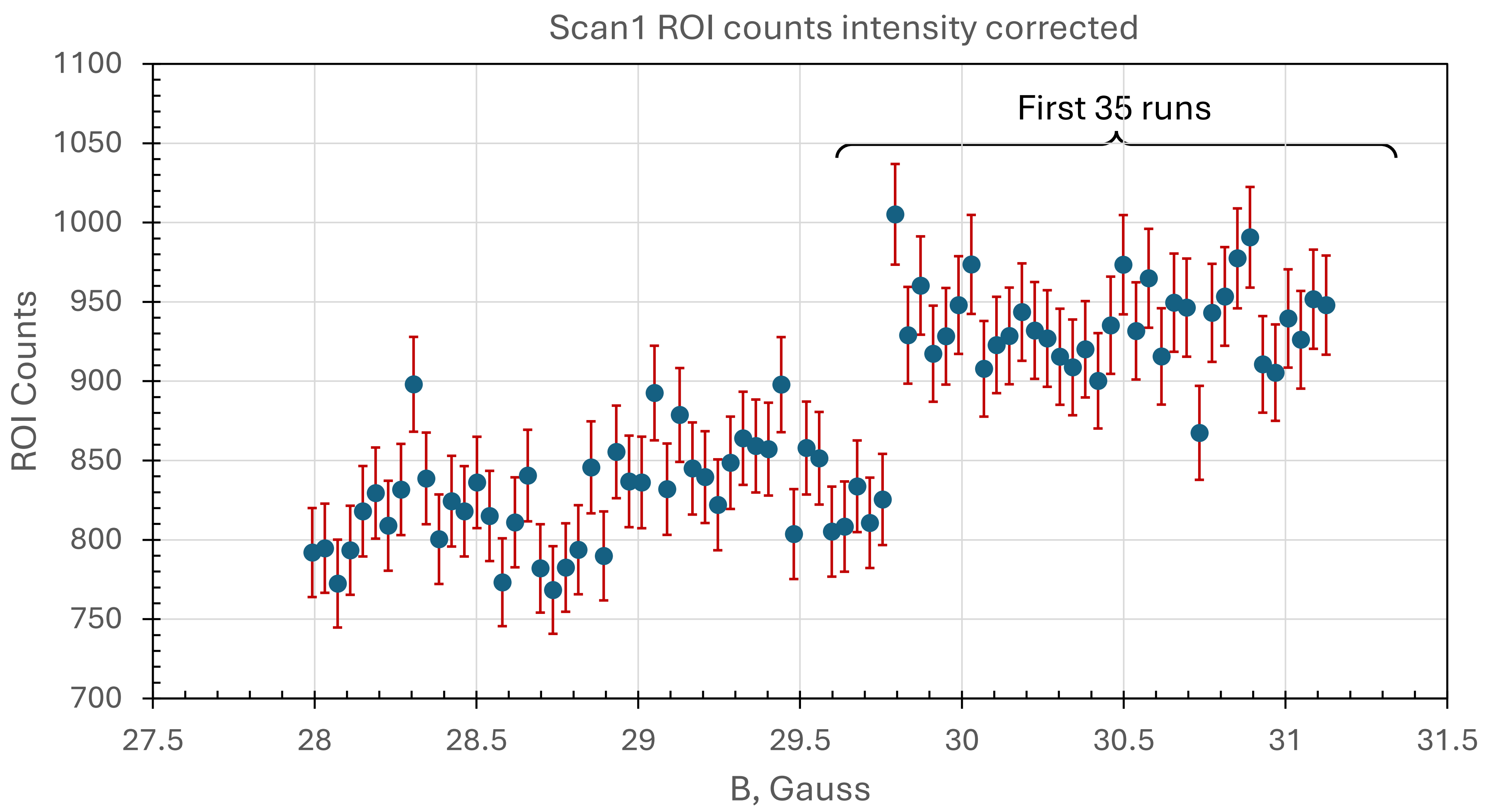
Yuri Kamyshkov / UTK

# OVERVIEW

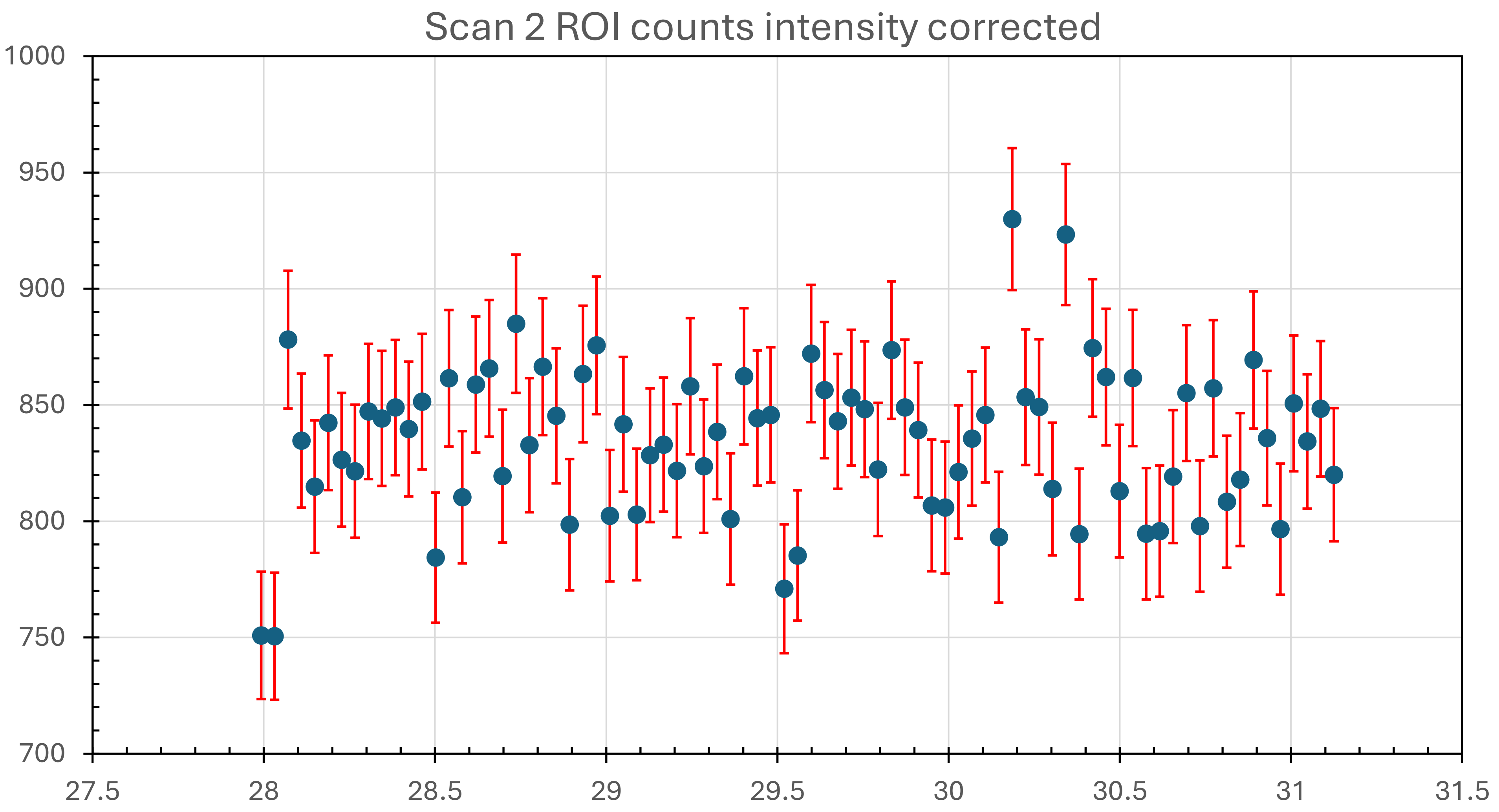
- All data runs are 30 min
- 1-st run started on Thursday Sept. 10 at 16:56
- Last run ended on Monday Sept. 14 at 12:33
- First sequential scan # 170127-170207
- Second random scan # 170212-170292
- Third central scan # 170293-170310
- We measured for 90 hours out of 96 allocated
- There are also few runs with “shutter closed”
- ICE magnet of CG-4 instrument was OFF



Intensity variation
GP-MON per sec
89000
88000
87000
86000
85000
84000
0
10
20
30
40
50
60
70
80
90
100
Time of active beam, hours

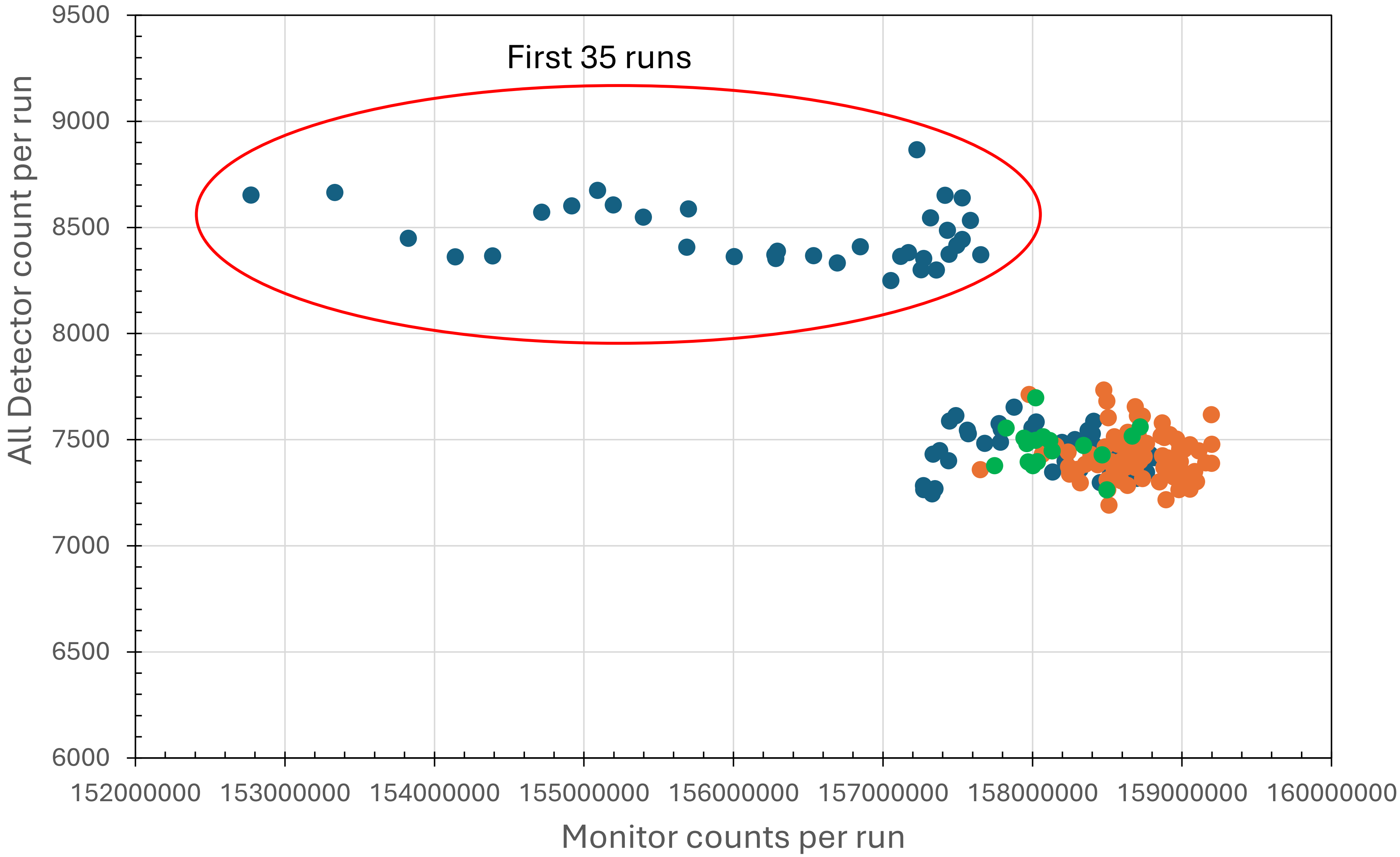



Detector count $\lesssim$ 900 / 1800 s = 0.5 / s ; error is ~ $\pm$ 30

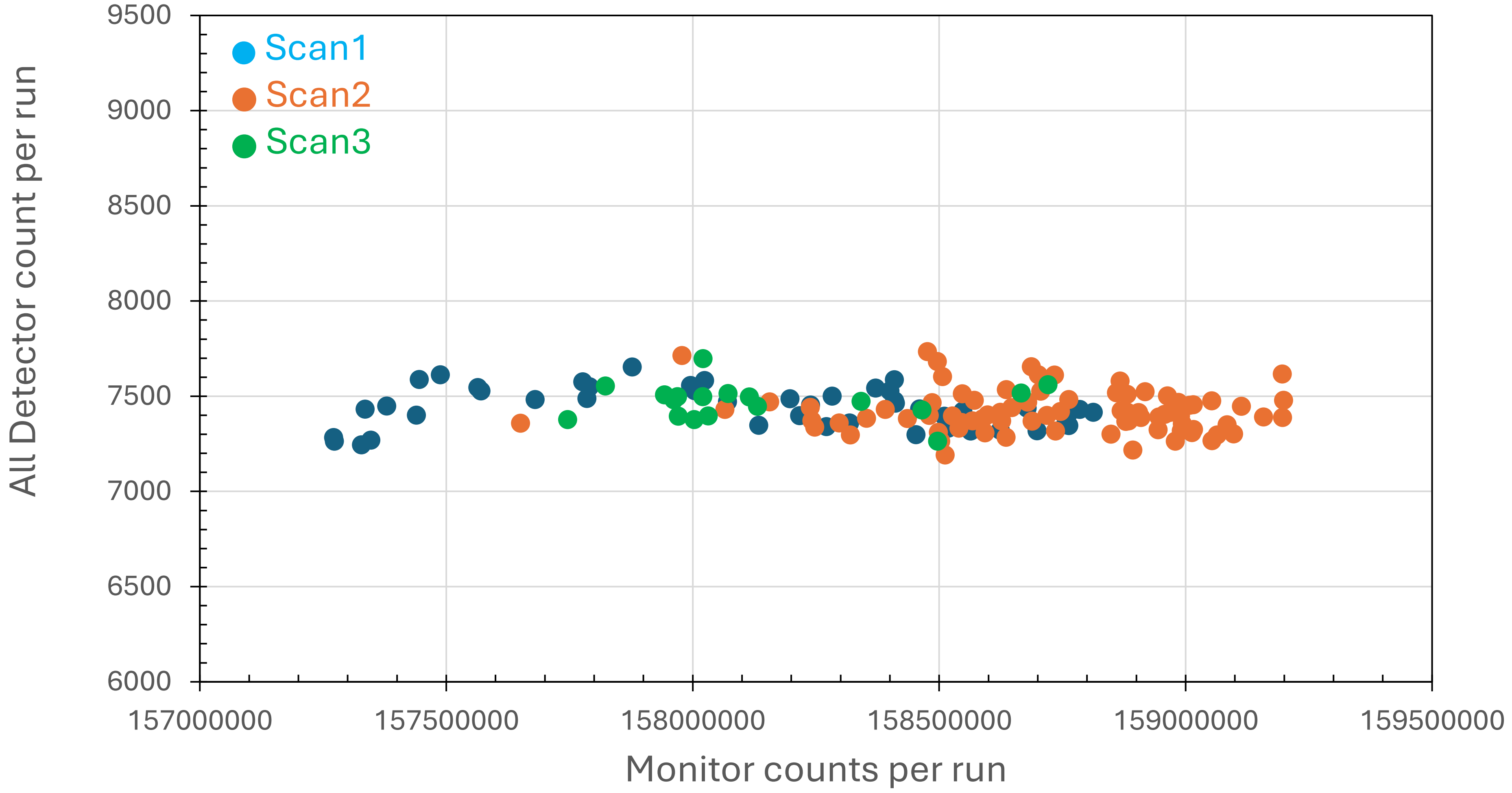


Scan 2 ROI counts intensity corrected
1000
950
900
850
800
750
700
27.5
28
28.5
29
29.5
30
30.5
31
31.5

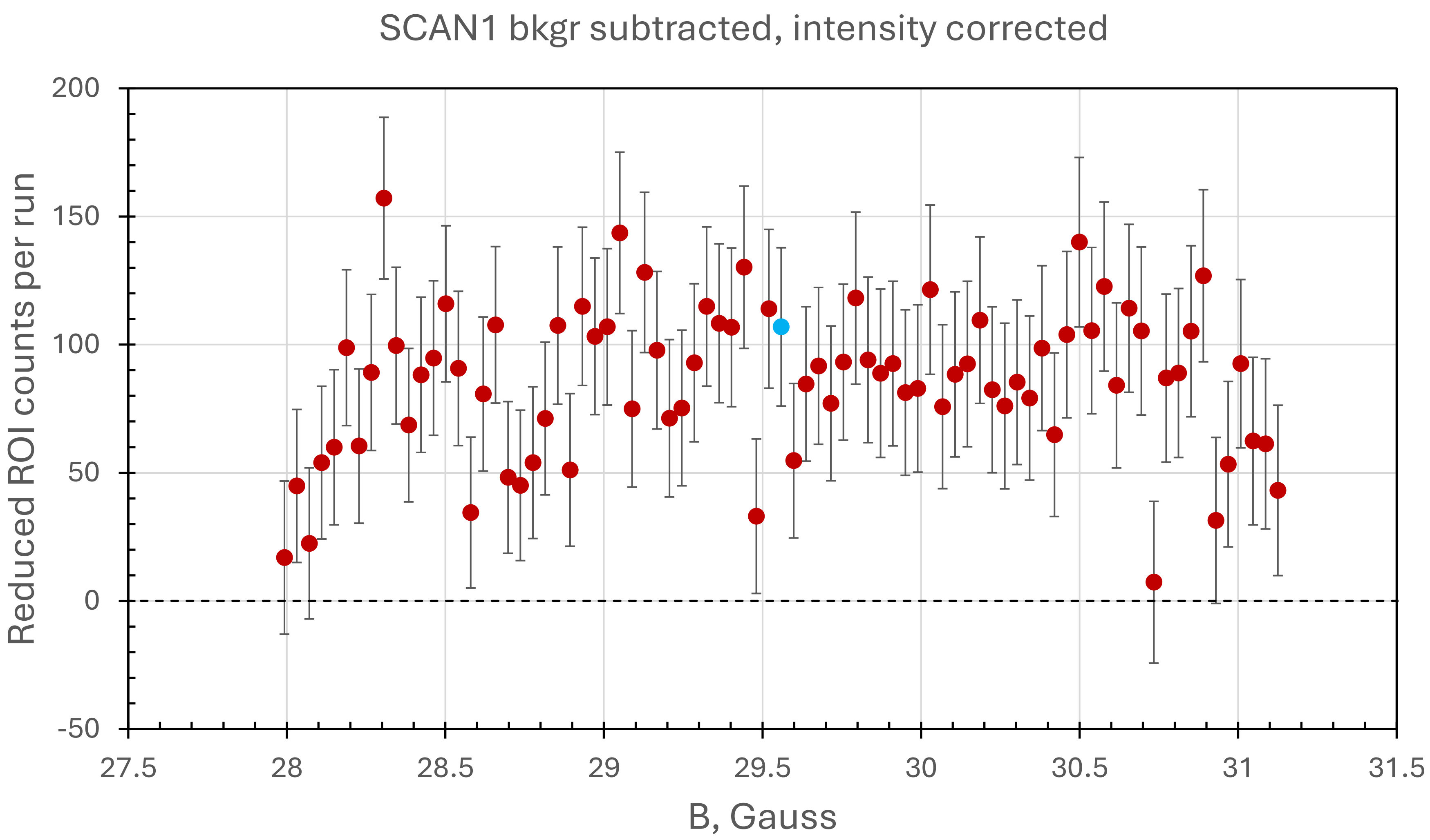
# Detector counts vs Monitor counts



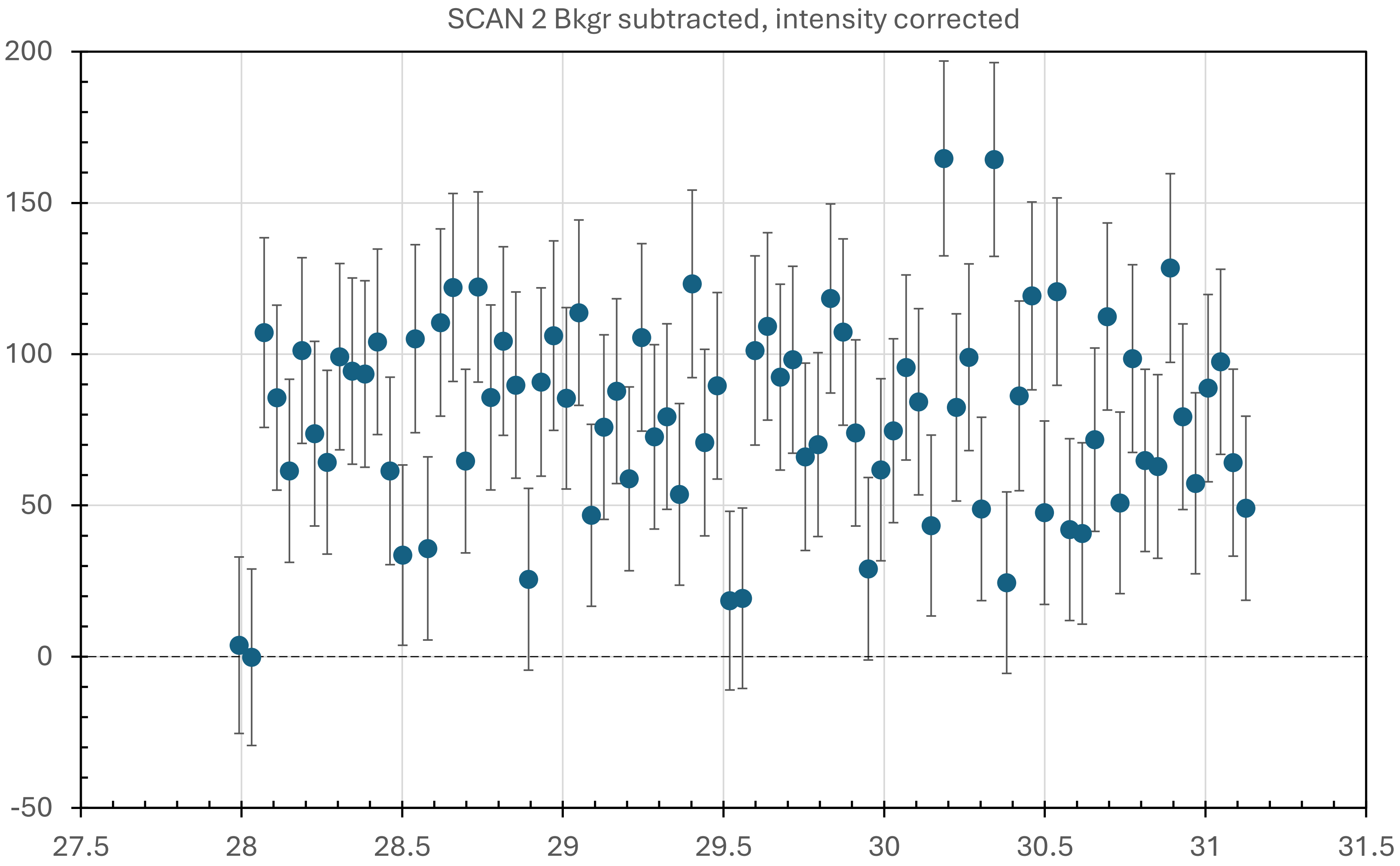
Without first 35 runs. Is detector counts proportional to monitor?

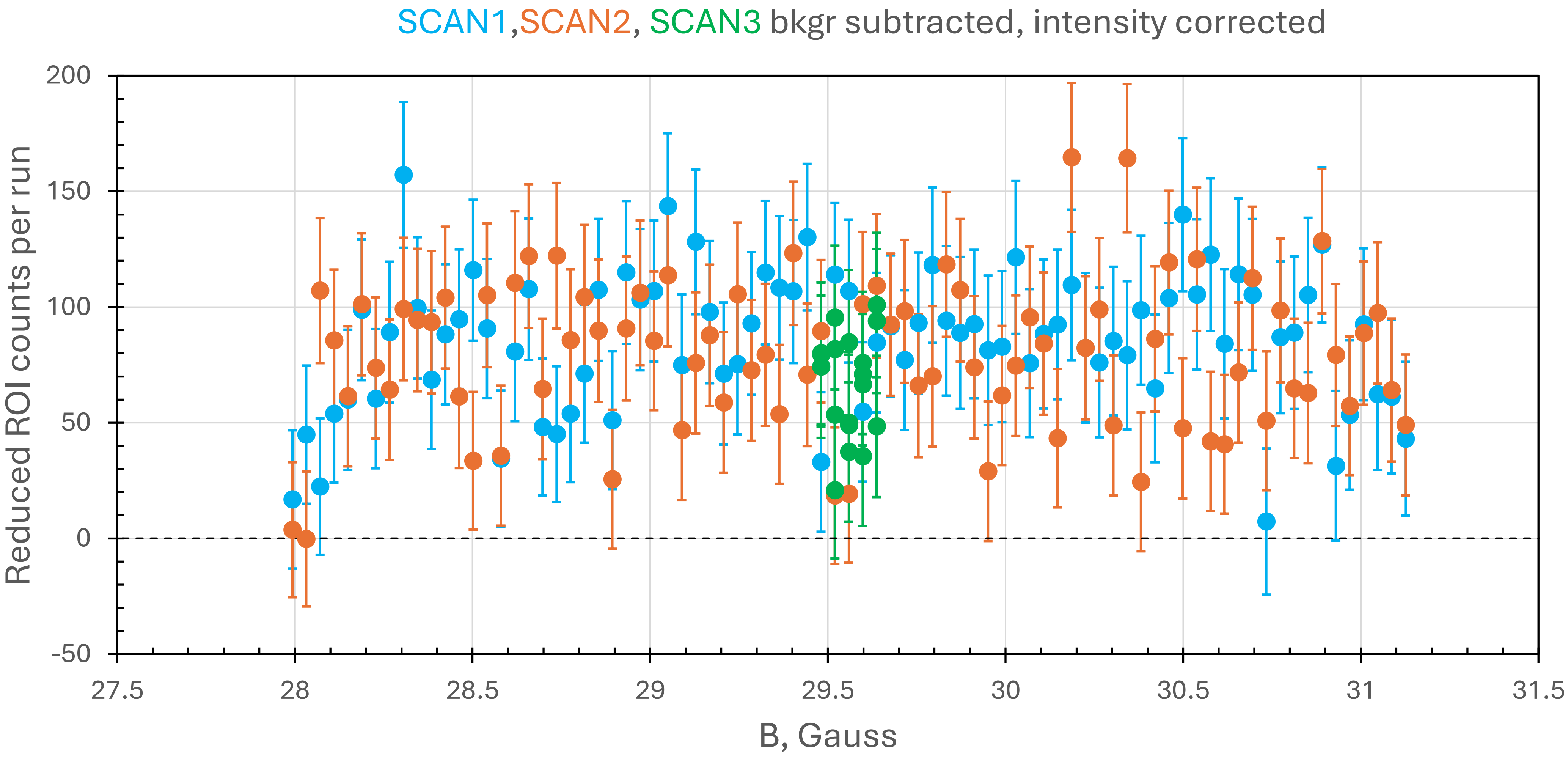



Detector counts are independent on Monitor: **detector background is not a GP-SANS beam background.**
With B-Poly and Cd we absorb GP-SANS beam but we have no control of the background in the hall.




First 35 points were due to background increase uniformly in the whole detector.
Blue point is position of expected nTMM peak is $\boldsymbol{V_F = \mu B}$ $(\Delta m = 0, B' = 0)$

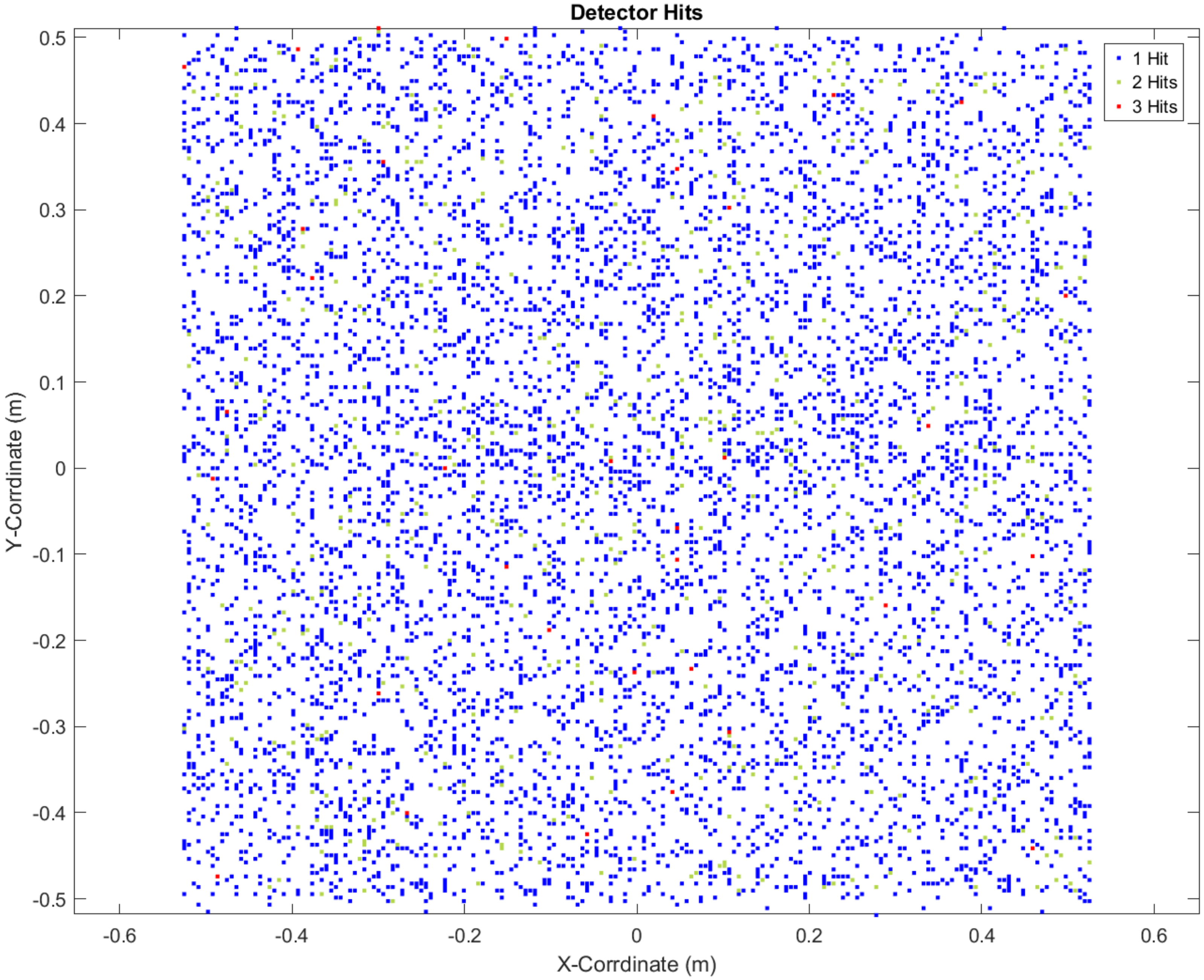

SCAN 2 Bkgr subtracted, intensity corrected
200
150
100
50
0
-50
27.5
28
28.5
29
29.5
30
30.5
31
31.5


SCAN1,SCAN2, SCAN3 bkgr subtracted, intensity corrected
Reduced ROI counts per run
B, Gauss
200
150
100
50
0
-50
27.5
28
28.5
29
29.5
30
30.5
31
31.5

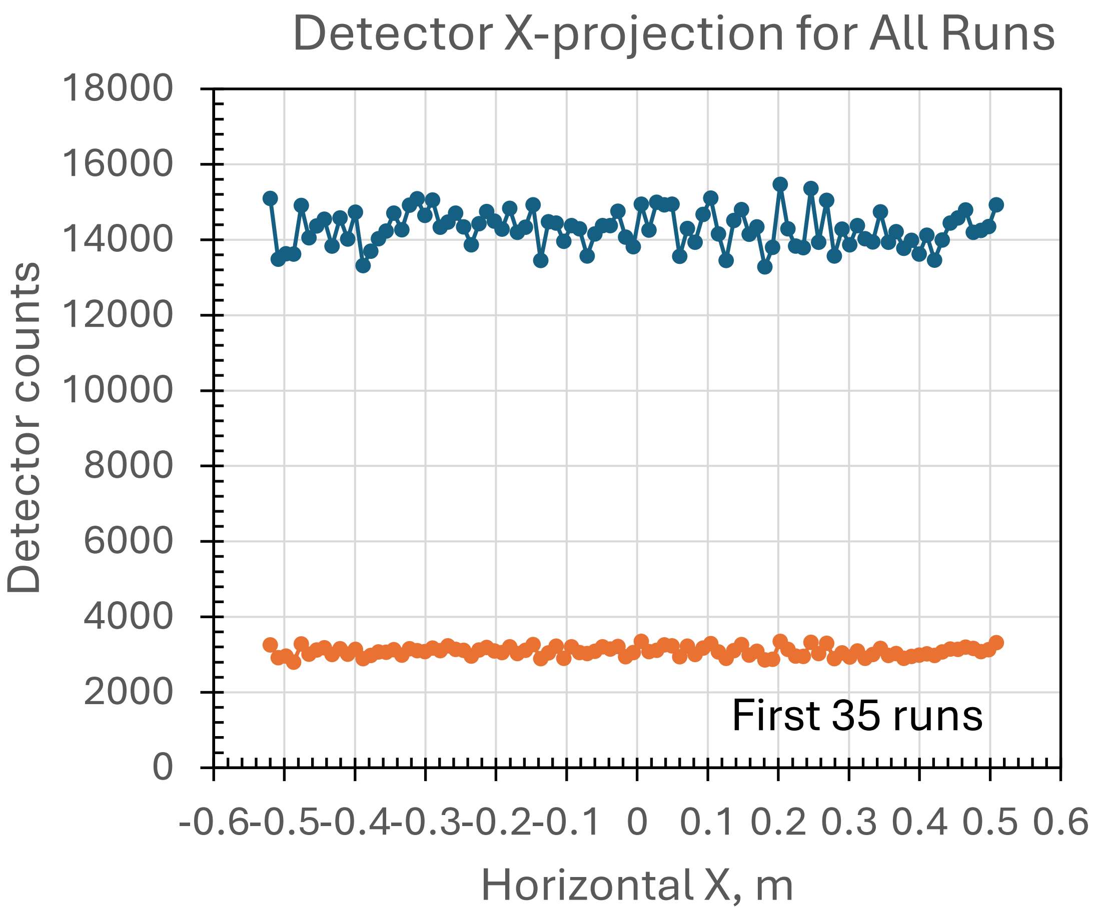
# No central peak in the detector

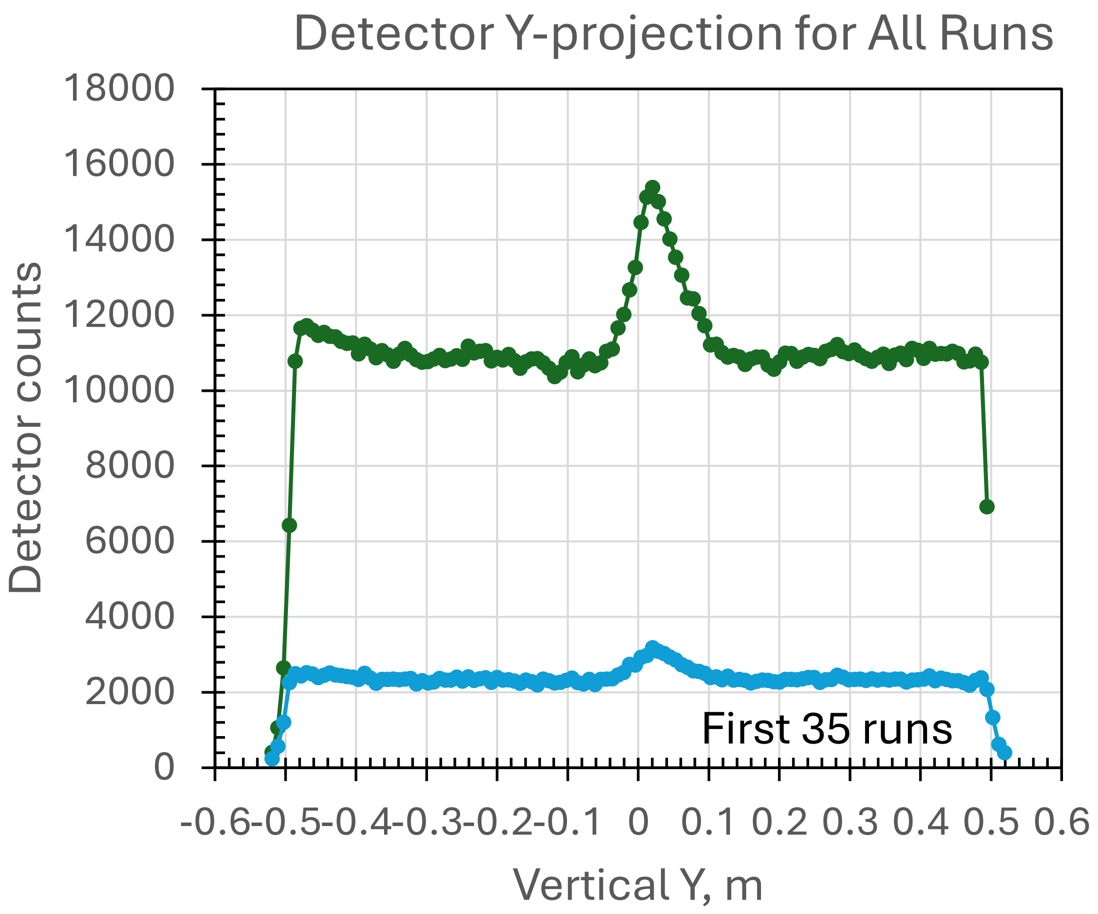
You need to have a sharp eye of Micheal Lumsdaine to find a horizontal band here

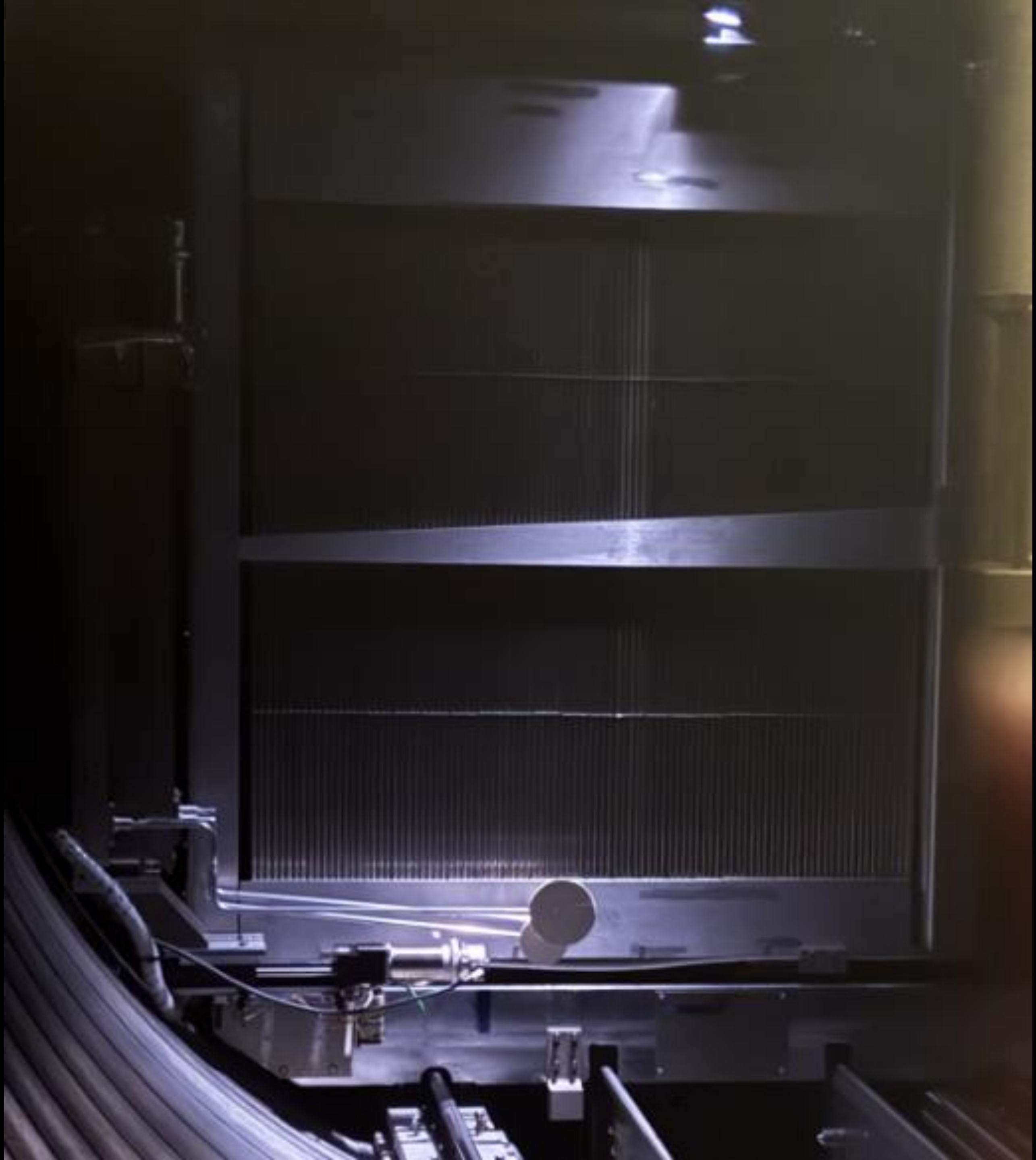
Run 170200 from Scan 1

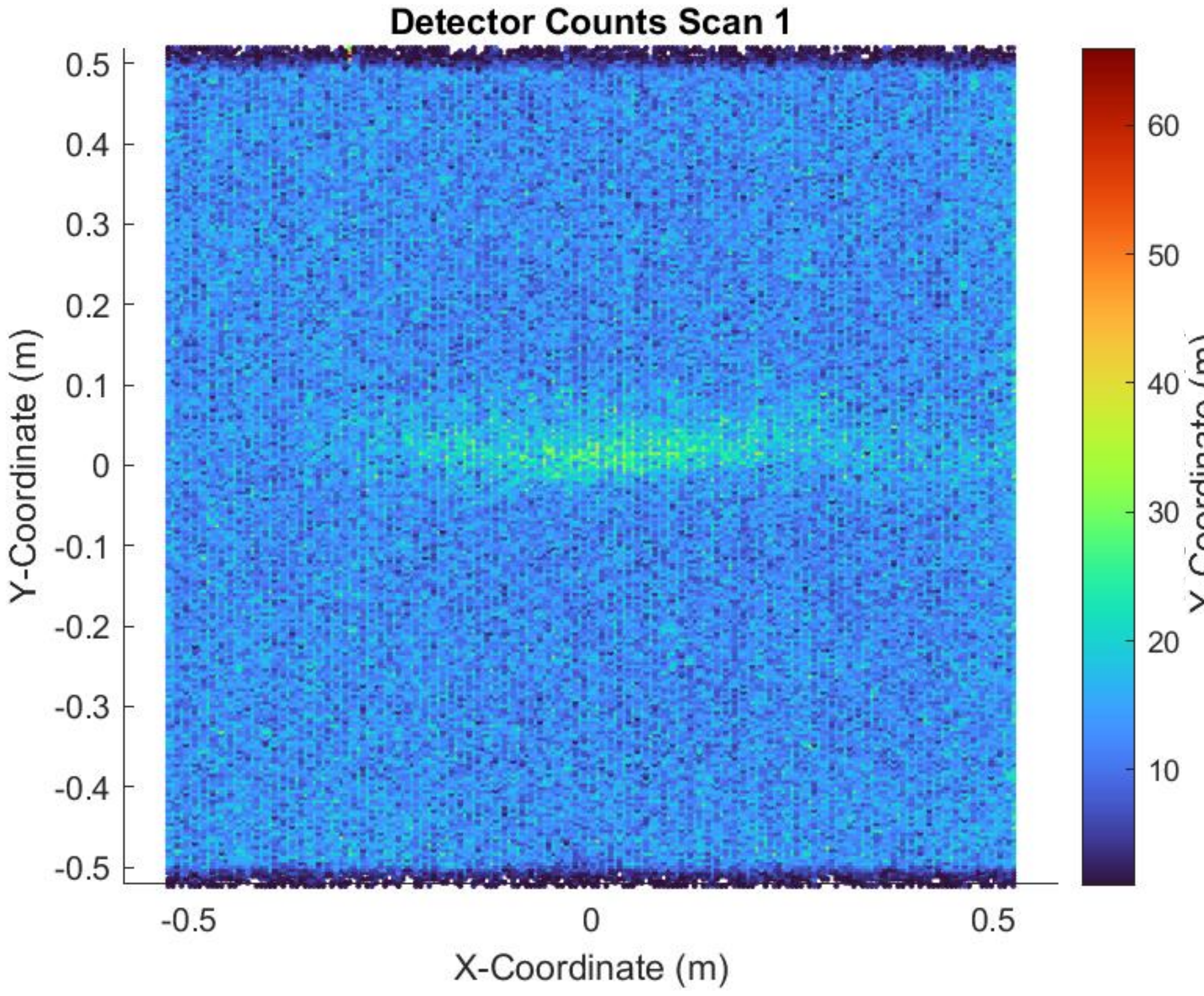


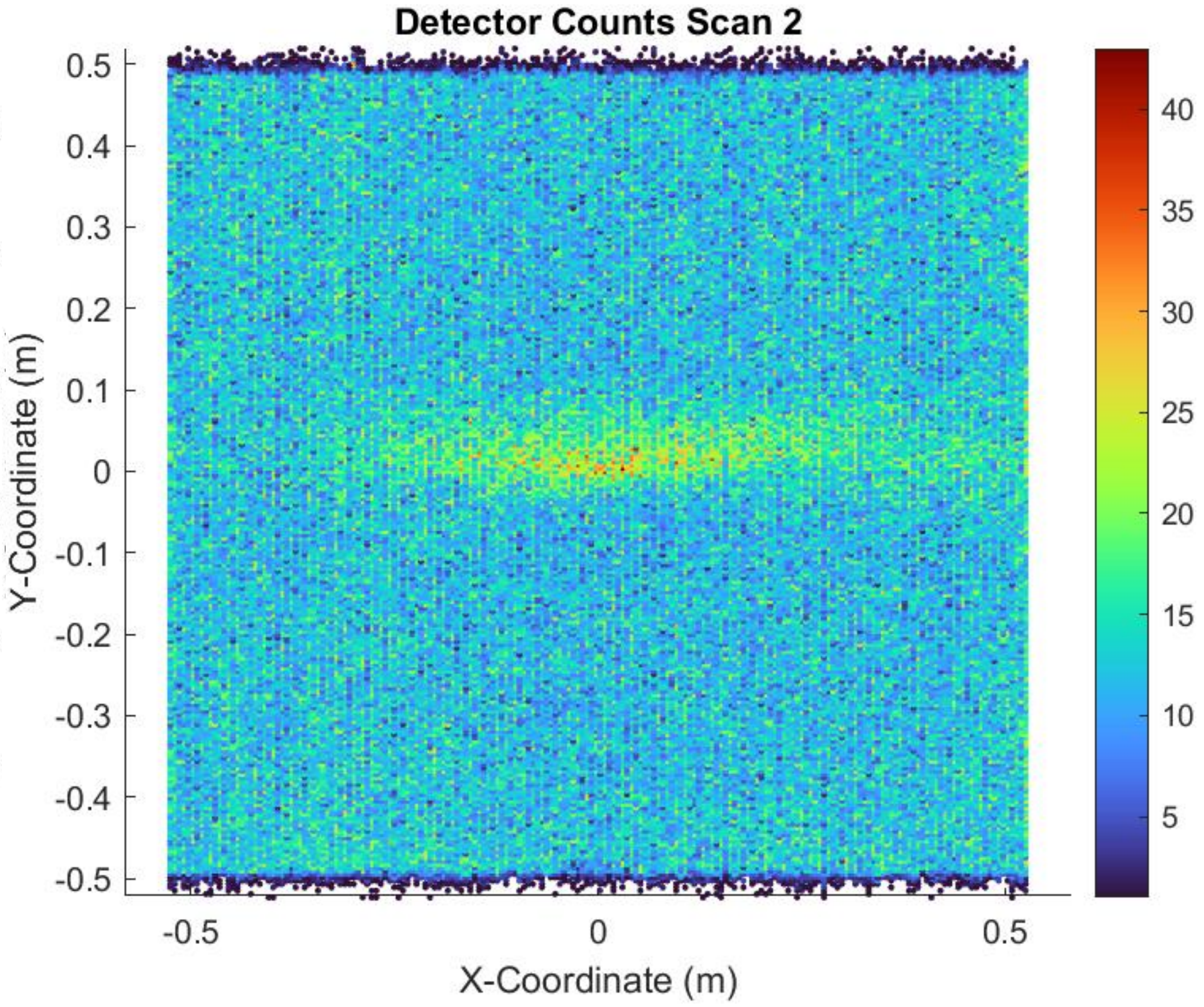
# X & Y detector distributions for all 180 runs



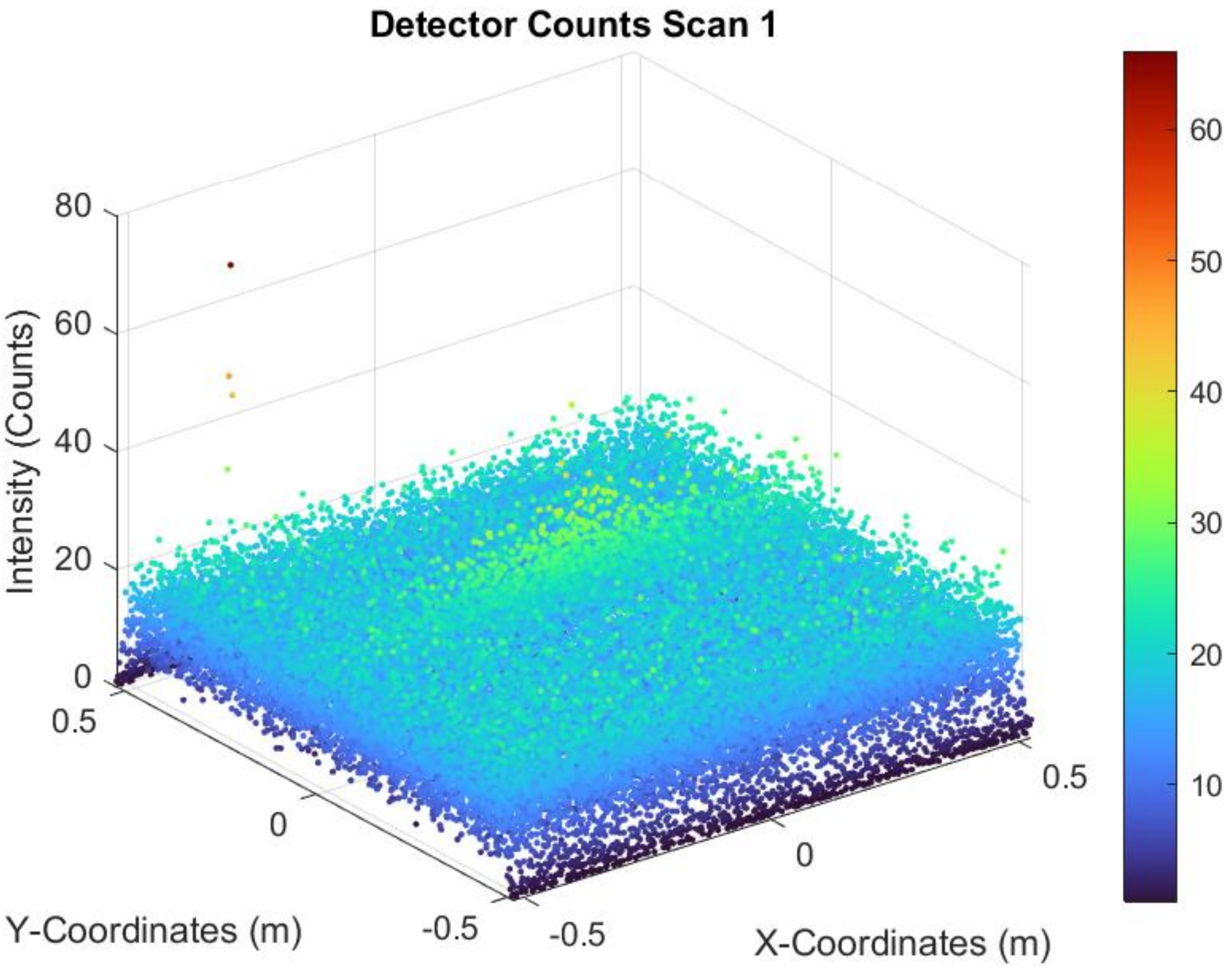



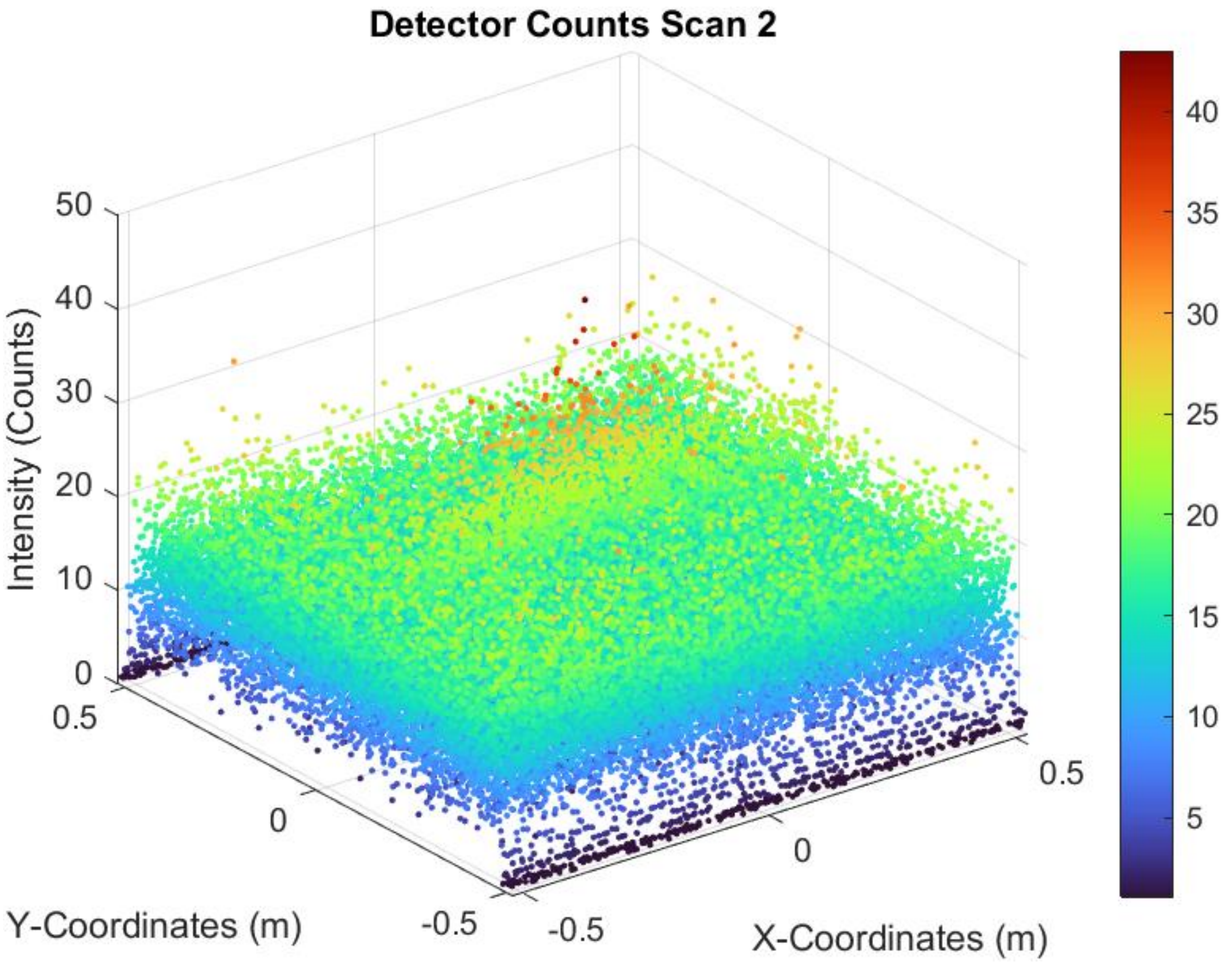




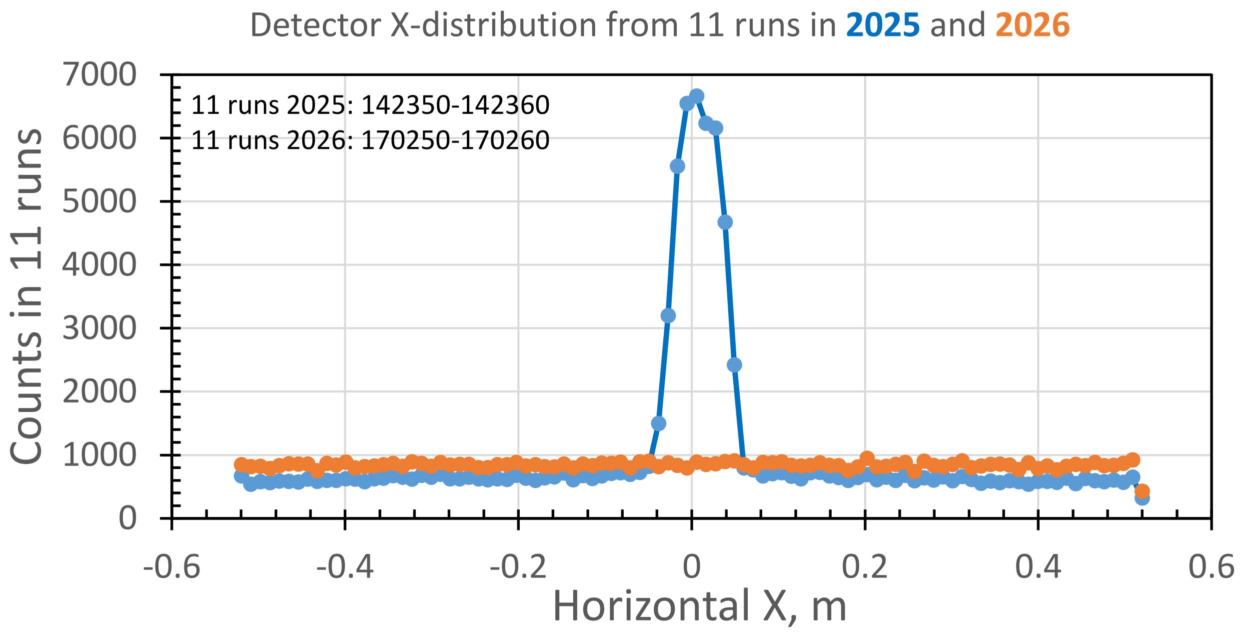



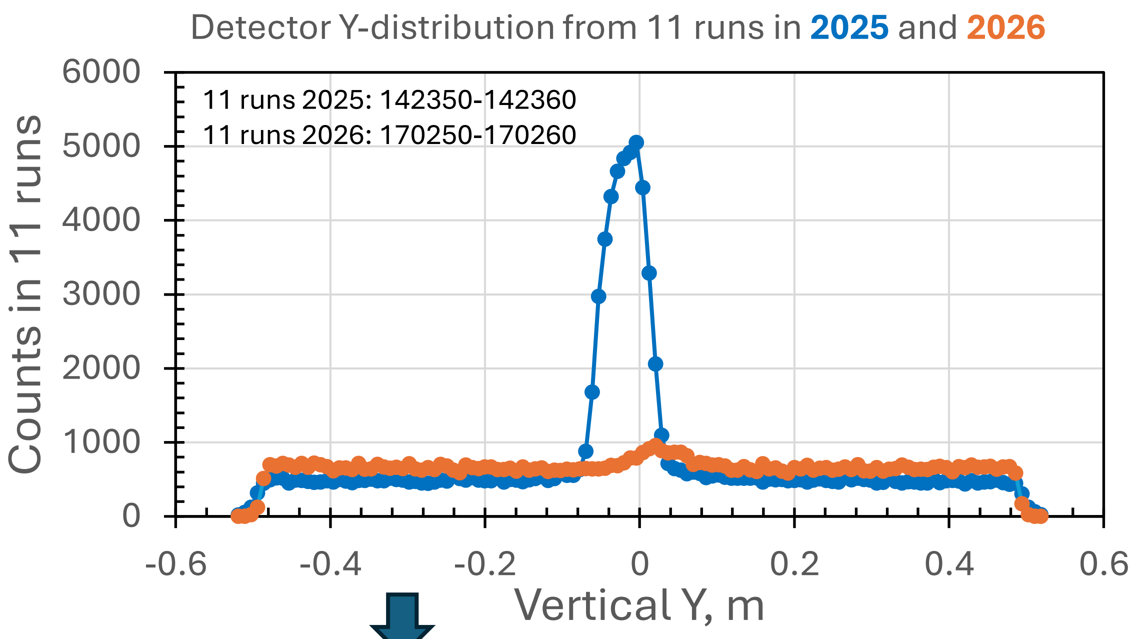

Michael Lumsdaine lumsdainem@gmail.com Sept 18, 2026




Michael Lumsdaine lumsdainem@gmail.com Sept 18, 2026


Detector X-distribution from 11 runs in 2025 and 2026
11 runs 2025: 142350-142360
11 runs 2026: 170250-170260
Counts in 11 runs
Horizontal X, m
0
1000
2000
3000
4000
5000
6000
7000
-0.6
-0.4
-0.2
0
0.2
0.4
0.6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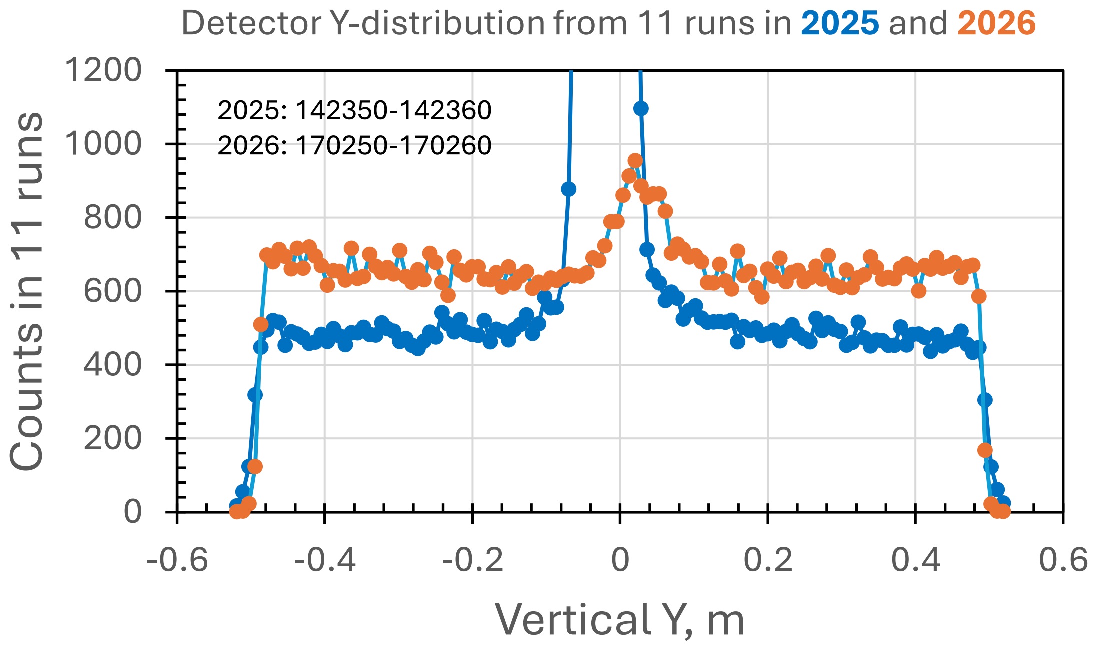
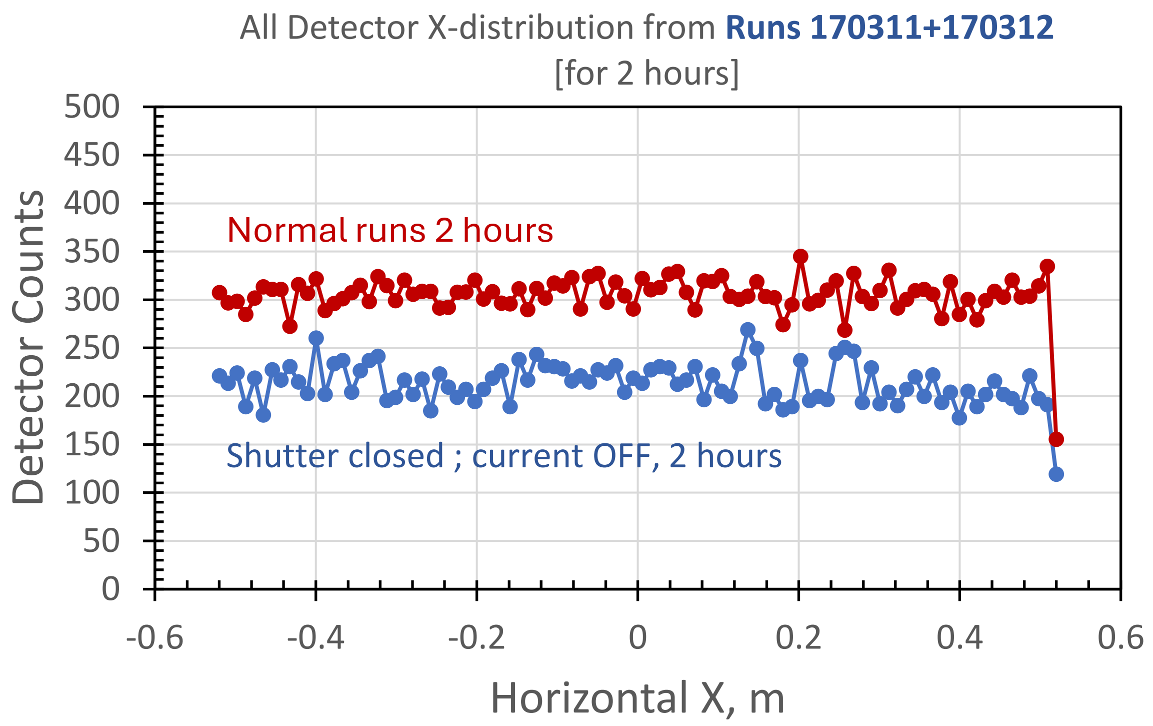
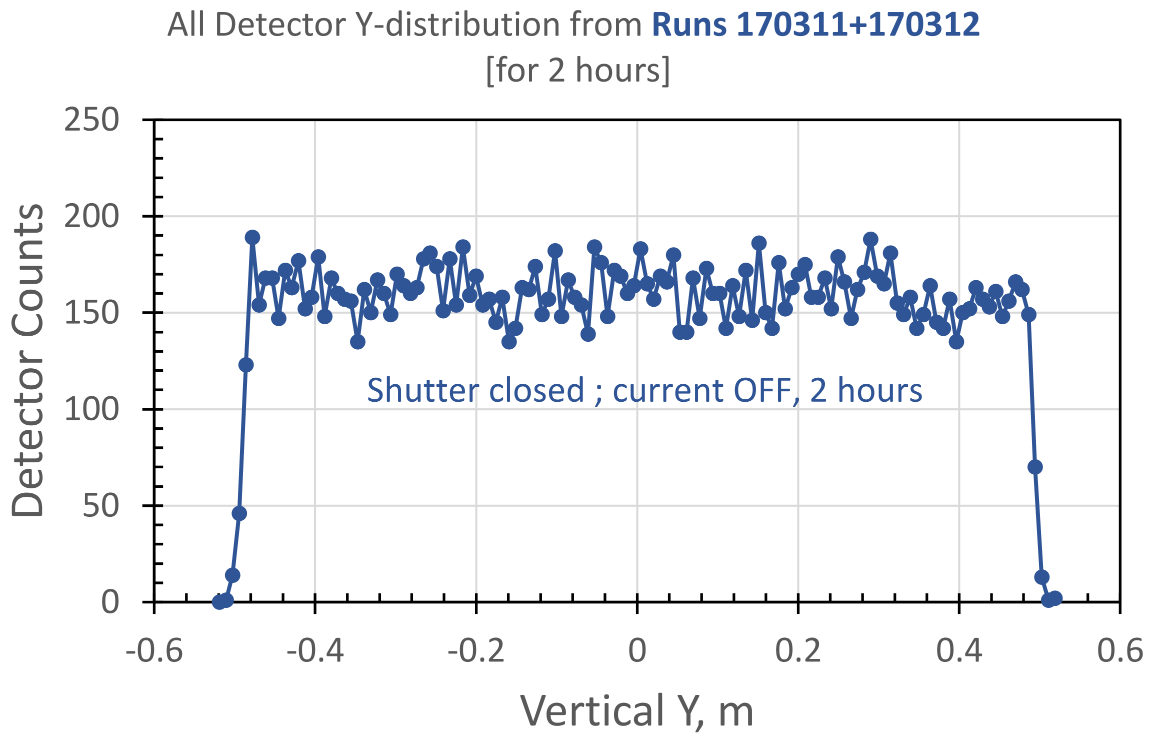
Counts in 11 runs
Vertical Y, m
0
1000
2000
3000
4000
5000
6000
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


Detector Y-distribution from 11 runs in 2025 and 2026
2025: 142350-142360
2026: 170250-170260
Counts in 11 runs
Vertical Y, m
0
200
400
600
800
1000
1200
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

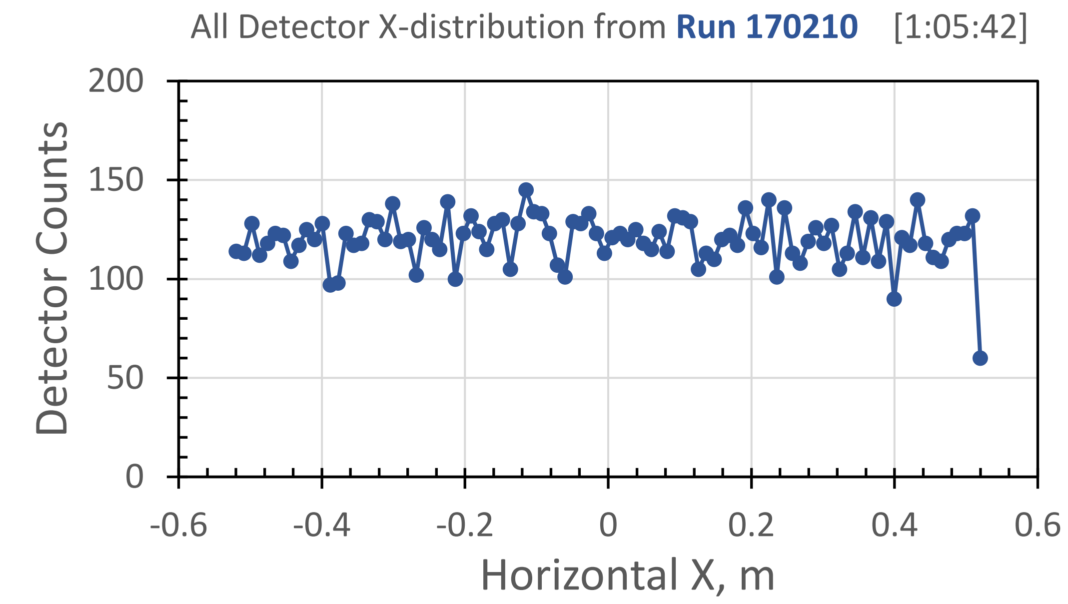
# Shutter closed, Current OFF 2-hours at the end of measurements

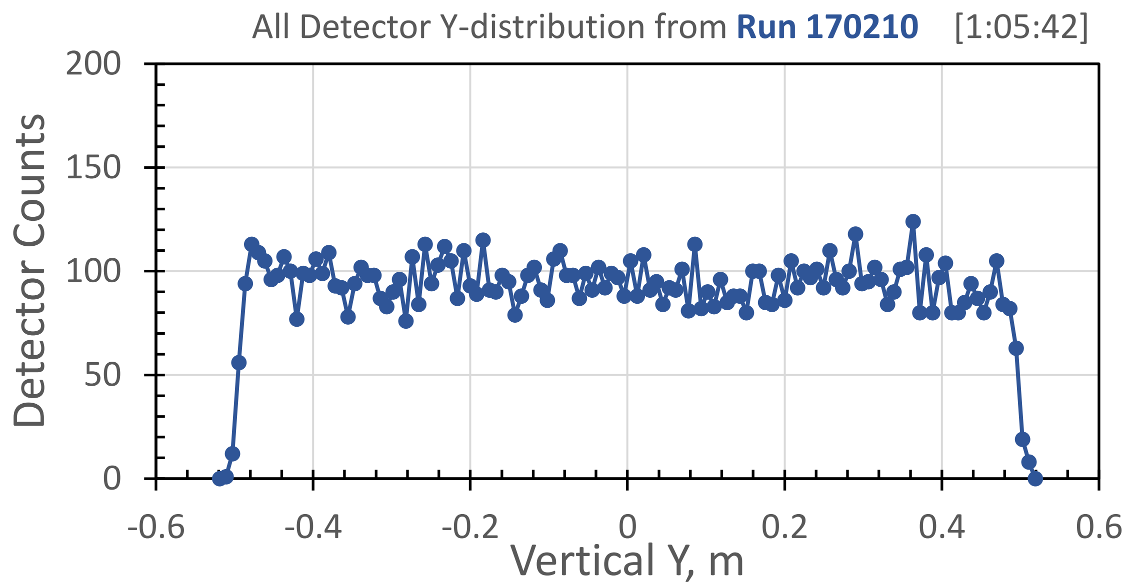


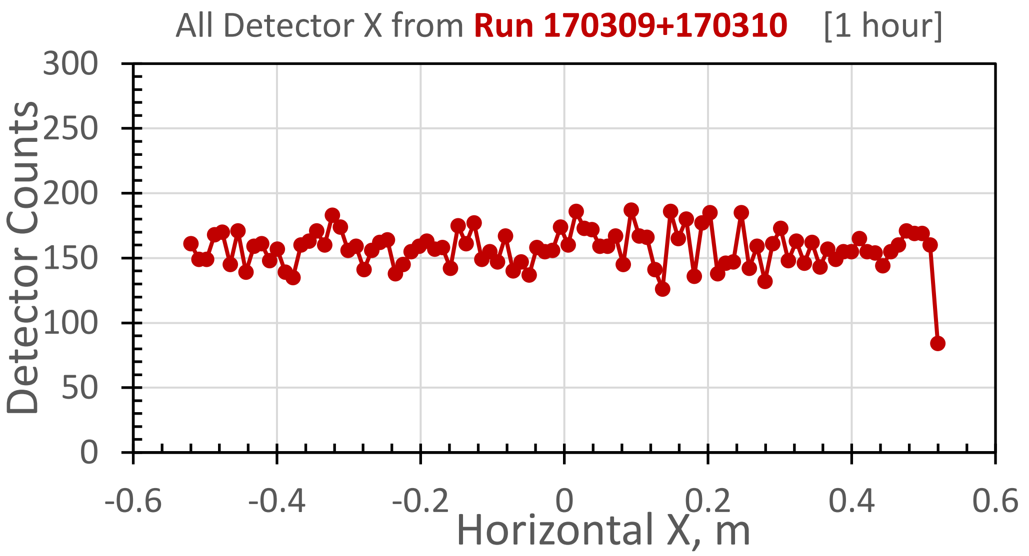

~ 2/3 of detector background are not coming from GP-SANS beam stopped by B-Poly and Cd

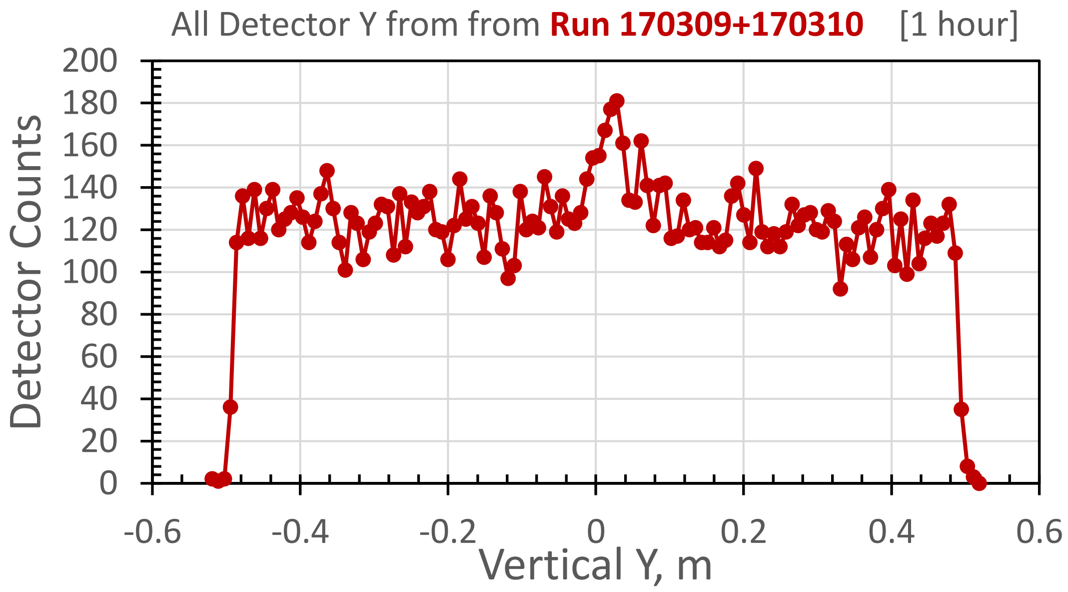
# Shutter closed, Current ON 1-hour 6 min




# Shutter open, Current ON 1-hour



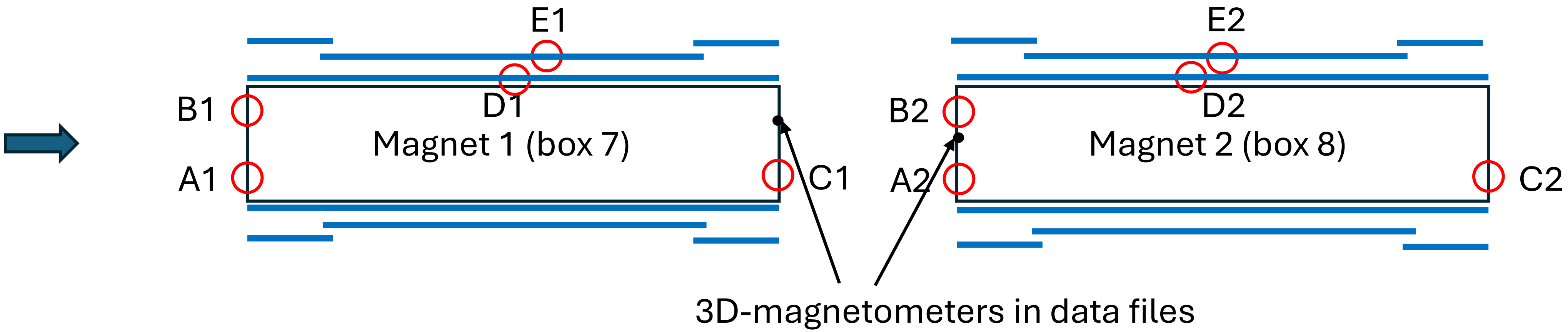



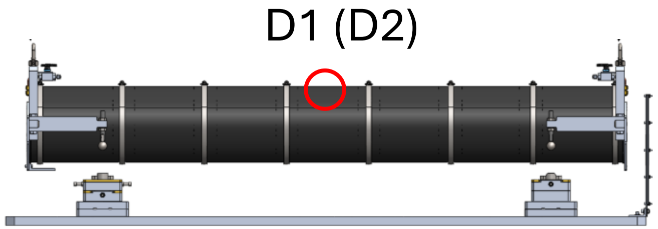
# No measurement with Shutter open, Current OFF

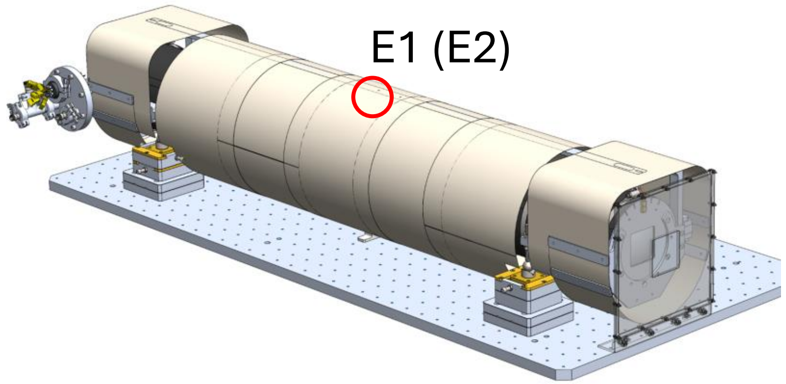
Origin of X-stripe in detector background (peak in Y) might be related to the presence of FAST neutrons in the beam with energies ~ 1 MeV. Neutrons scattered from the mirror of the "optical filter" and then scattered in Borated Poly that can not sufficiently moderate them. Possibly Charlie Snow can easily simulate that in GEANT-4

July 13, 2026

# nTMM-2 Thermocouple Location Schematic 2026

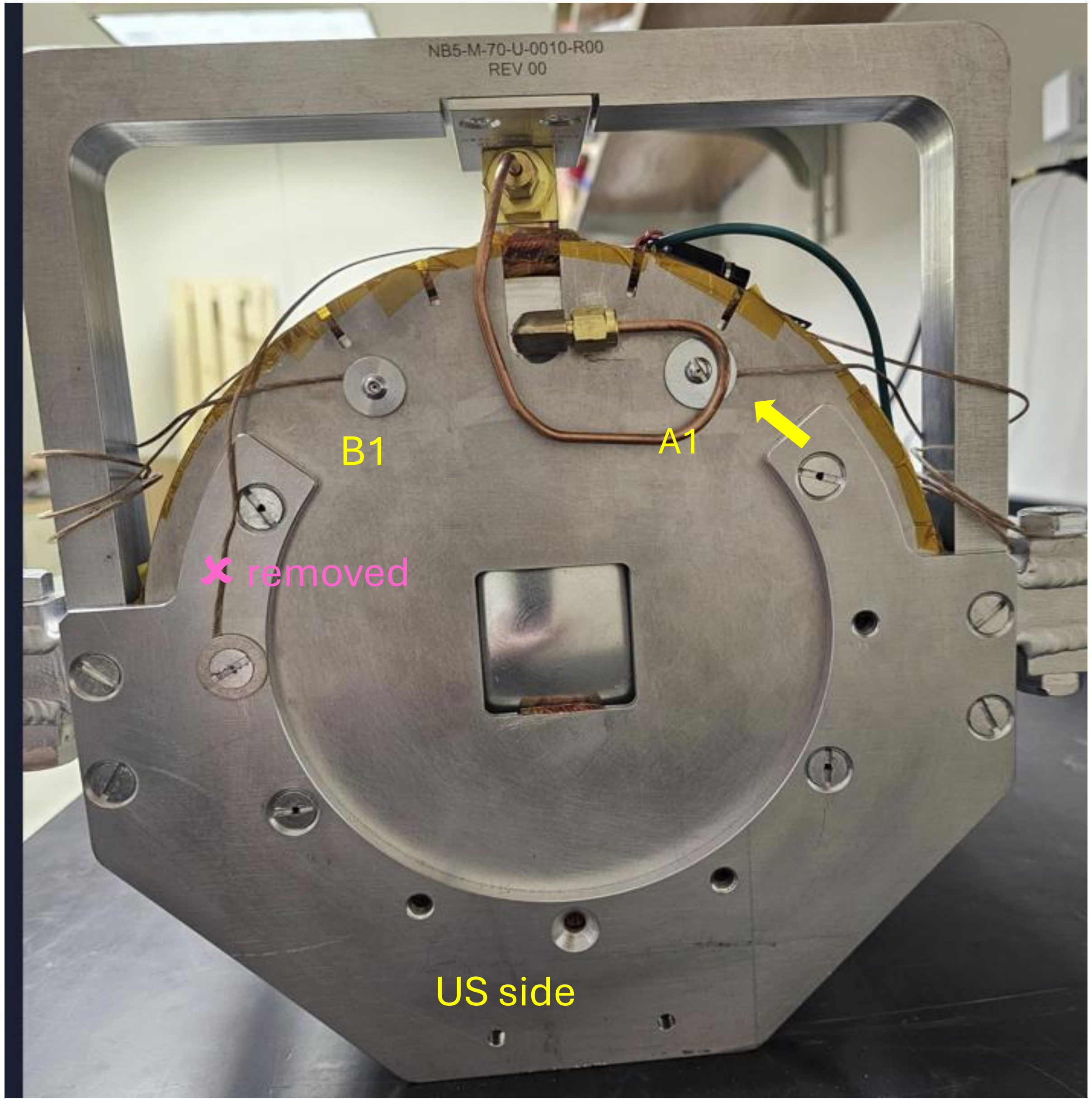


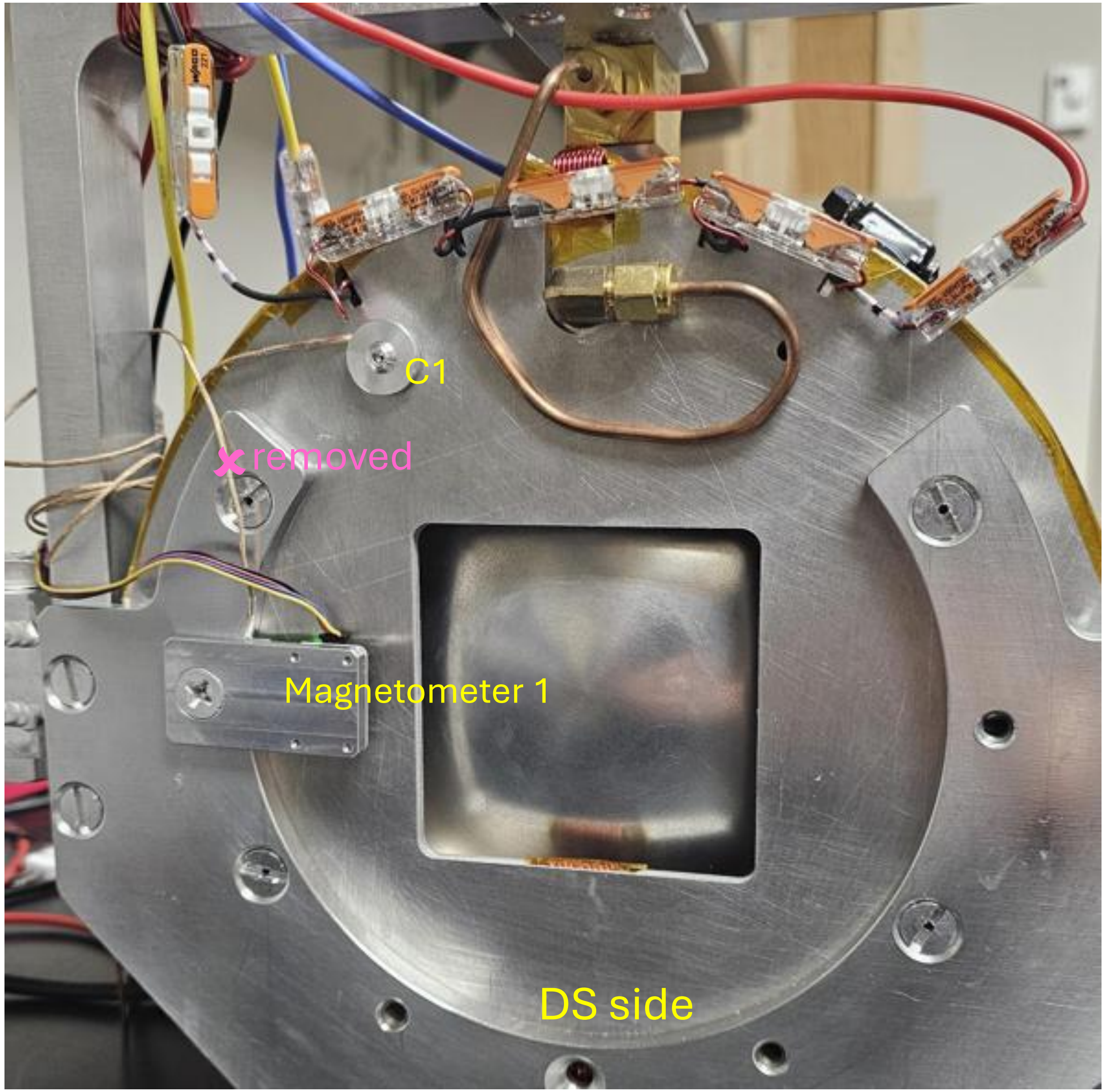




A1, A2 , D1, D2 thermocouples are in data files

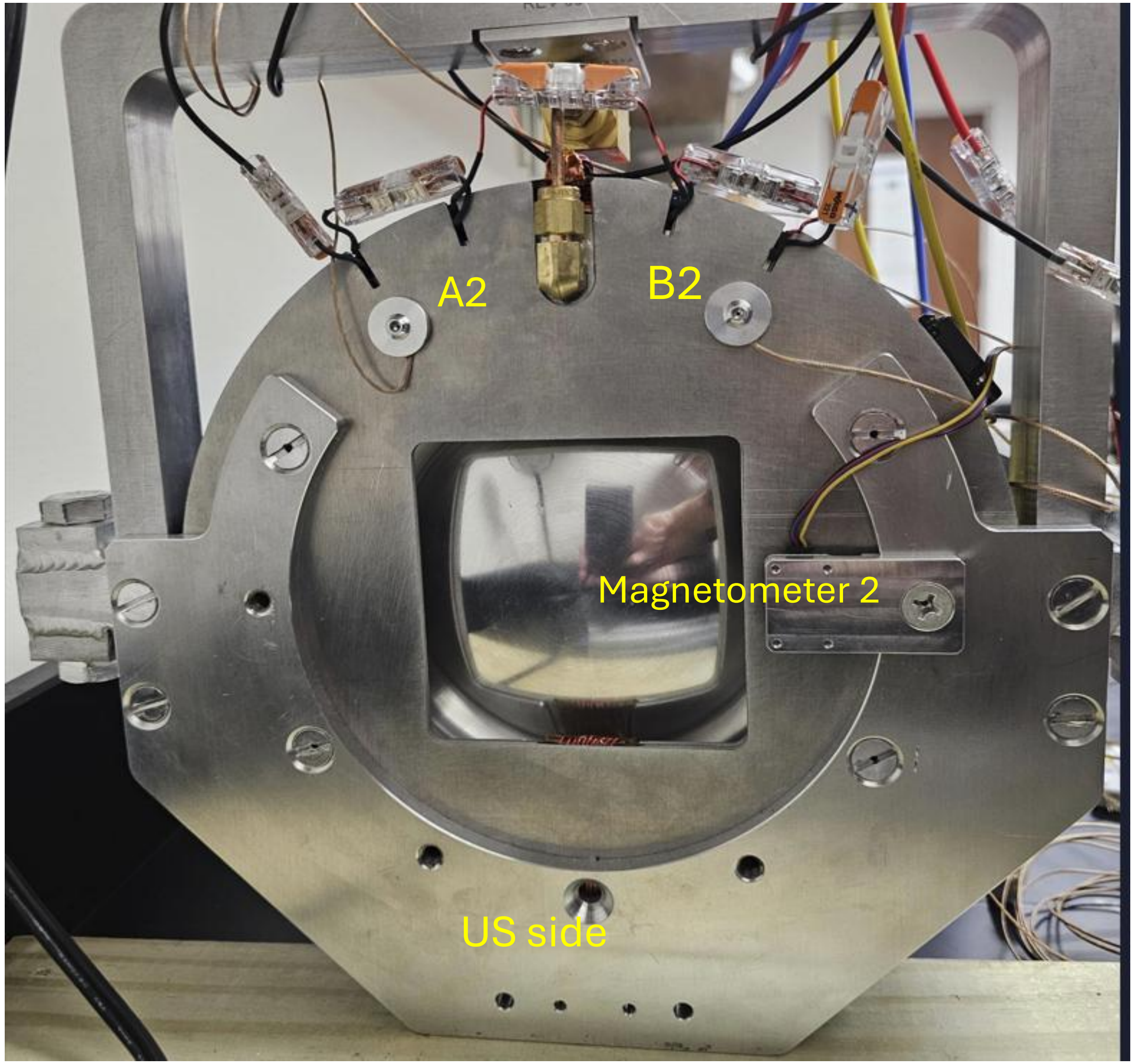
# 2026 Thermocouple's location on Magnet 1 (in box 7)

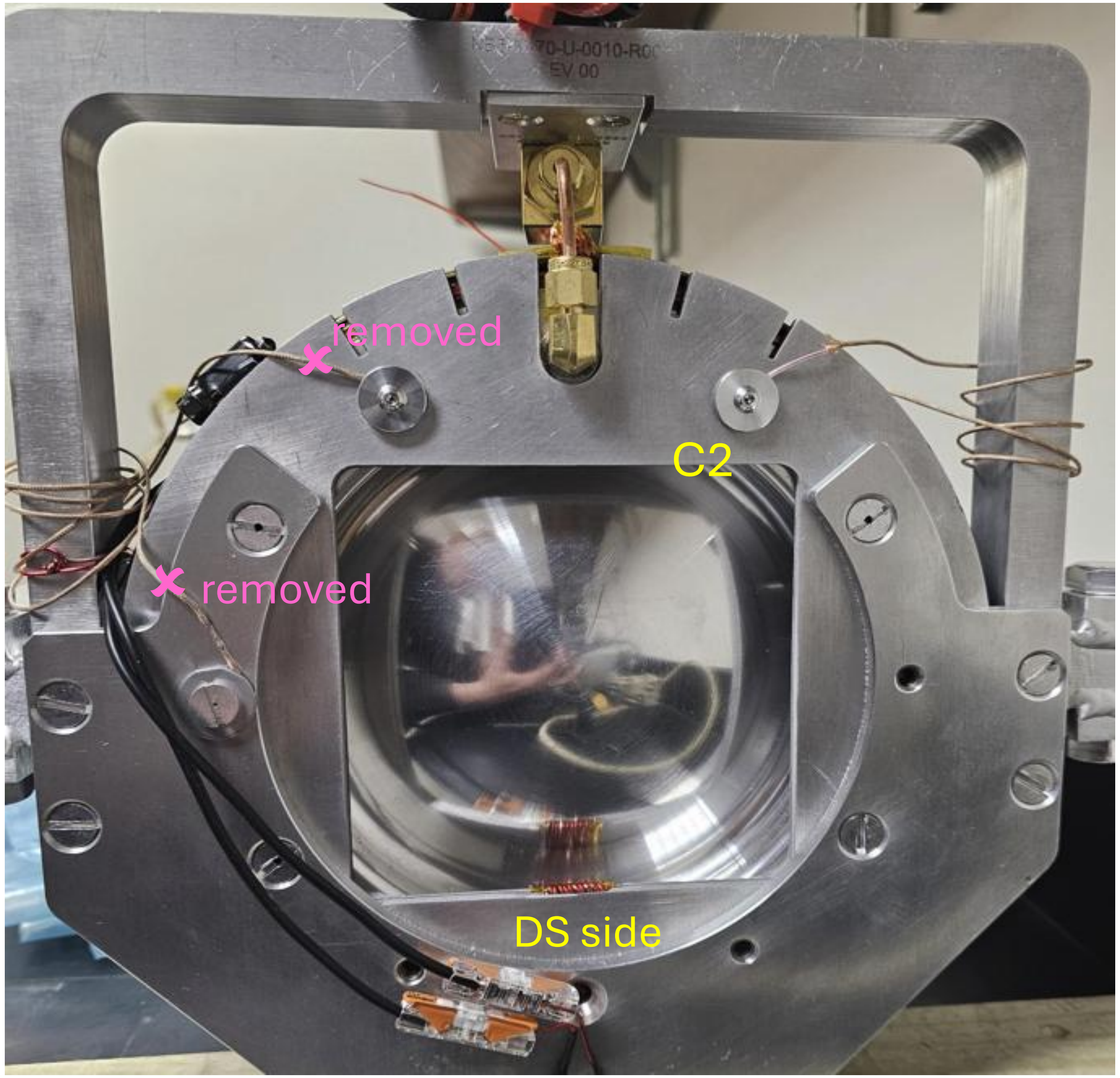


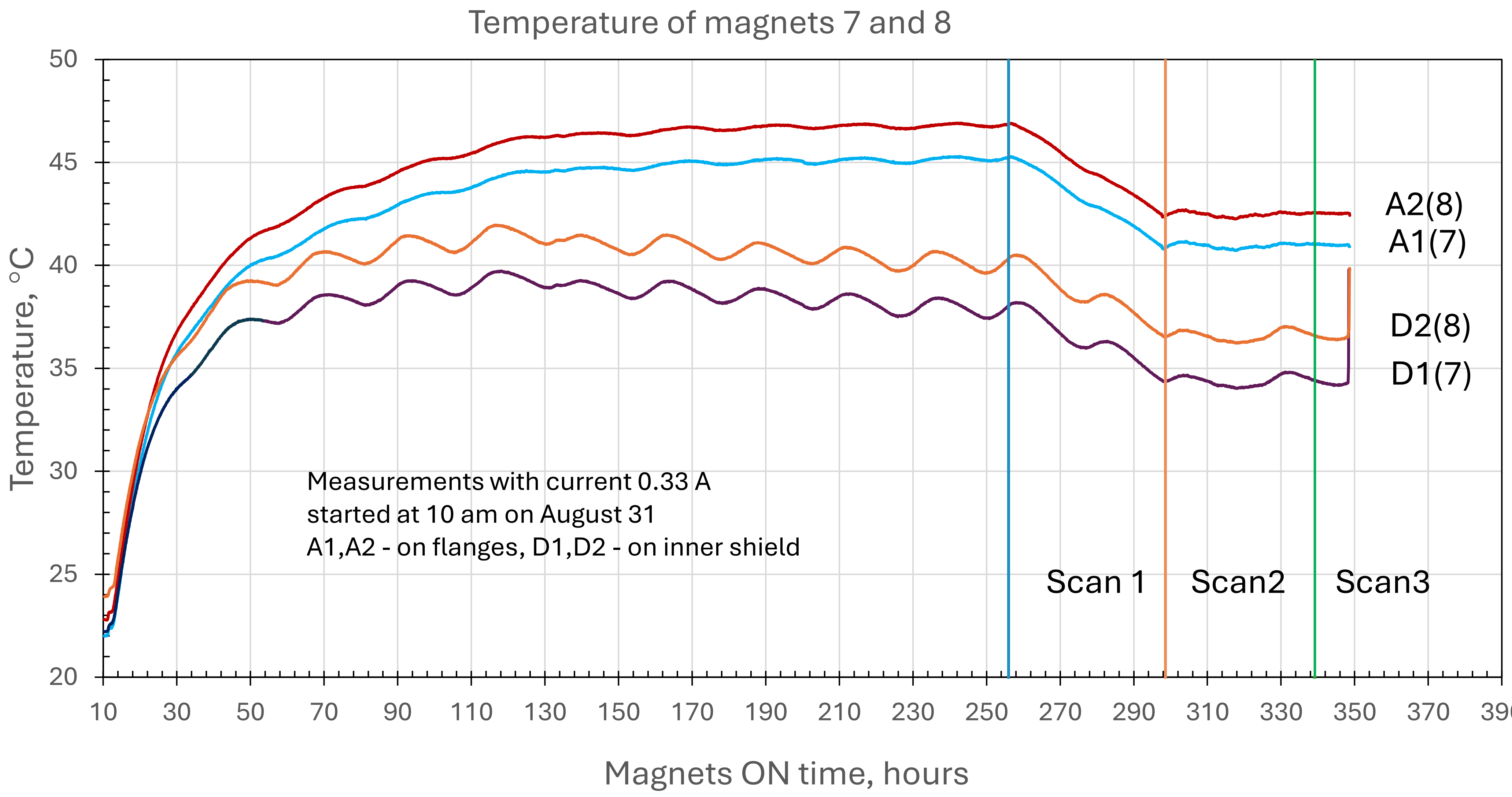



August 3, 2026

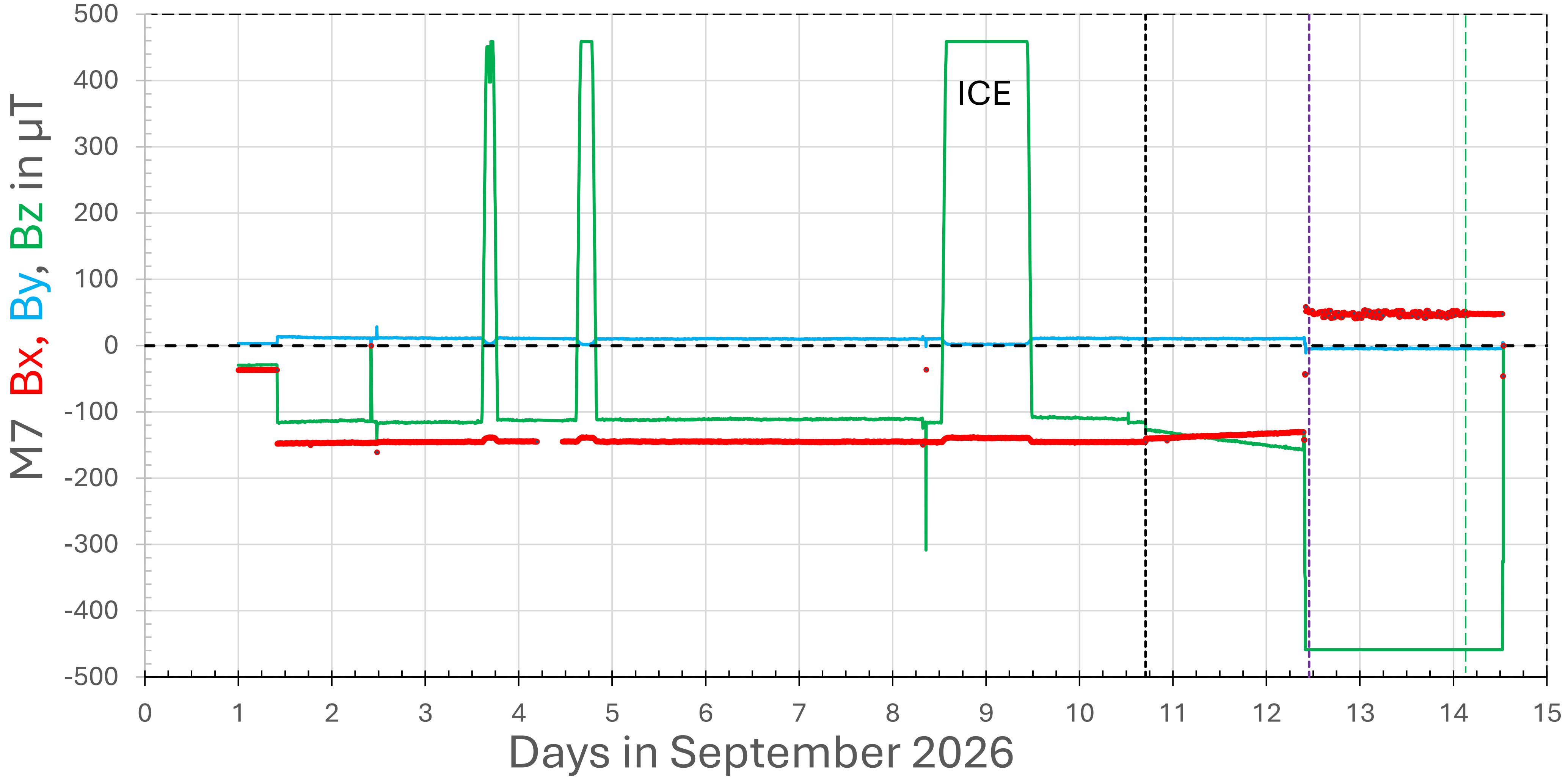
# 2026 Thermocouple's location on Magnet 2 (in box 8)



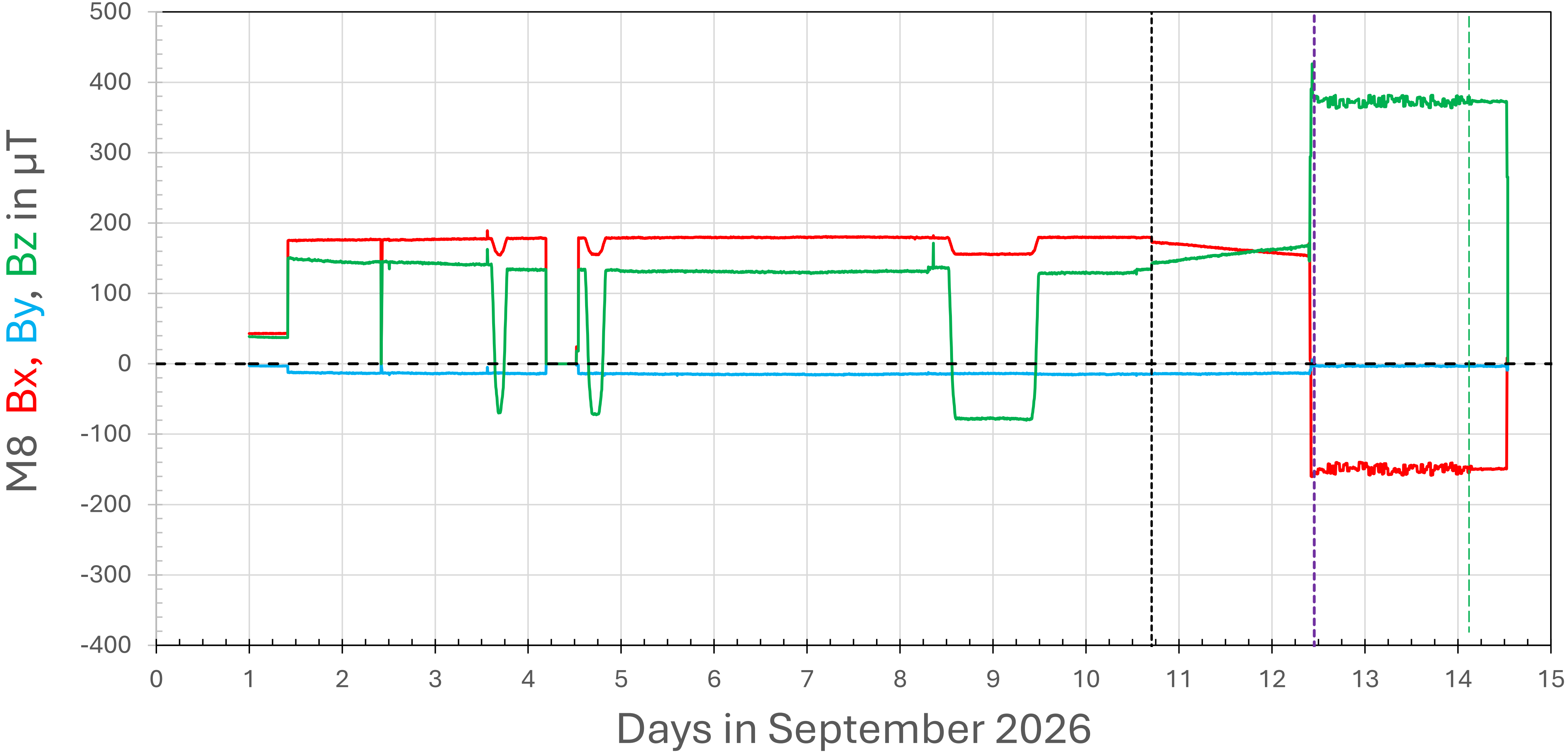




Temperature of magnets 7 and 8
Temperature, °C
50
45
40
35
30
25
20
10
30
50
70
90
110
130
150
170
190
210
230
250
270
290
310
330
350
370
390
Magnets ON time, hours
Measurements with current 0.33 A
started at 10 am on August 31
A1,A2 - on flanges, D1,D2 - on inner shield
Scan 1
Scan2
Scan3
A2(8)
A1(7)
D2(8)
D1(7)

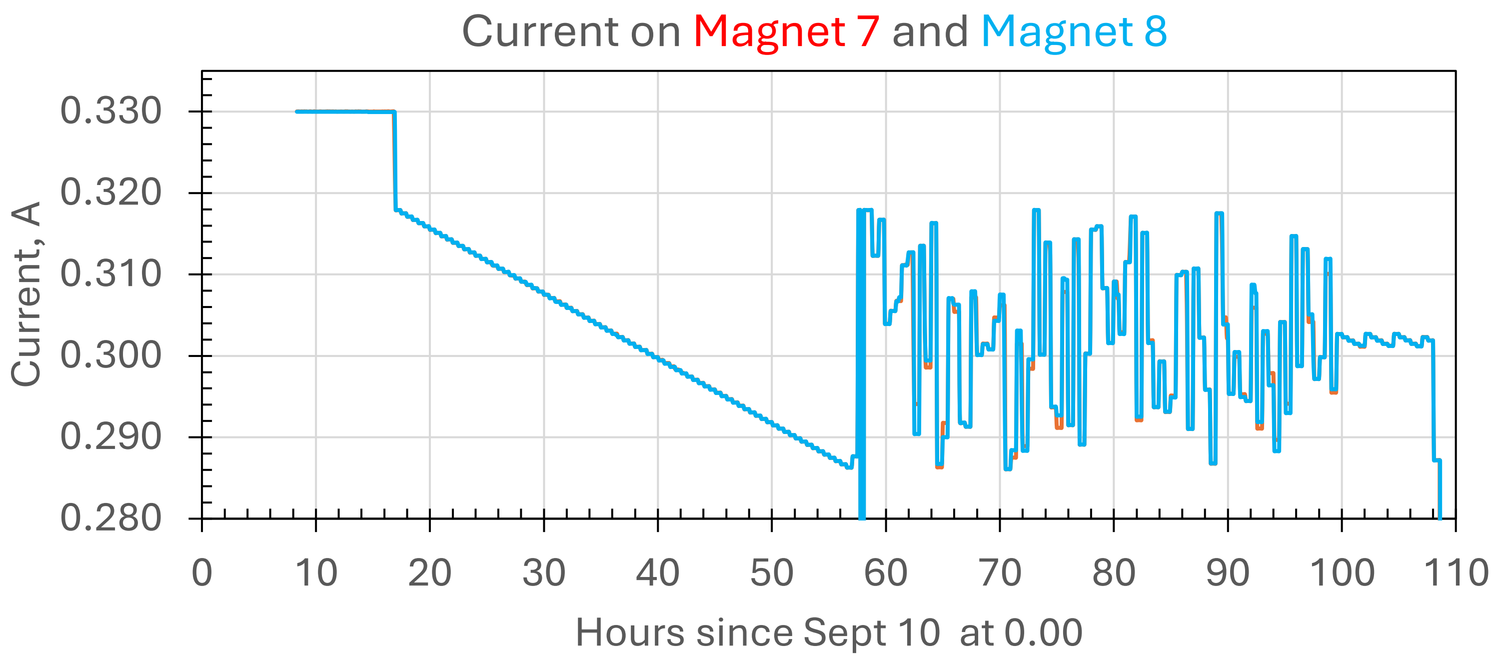
# 3D CHIP magnetometer on box 7

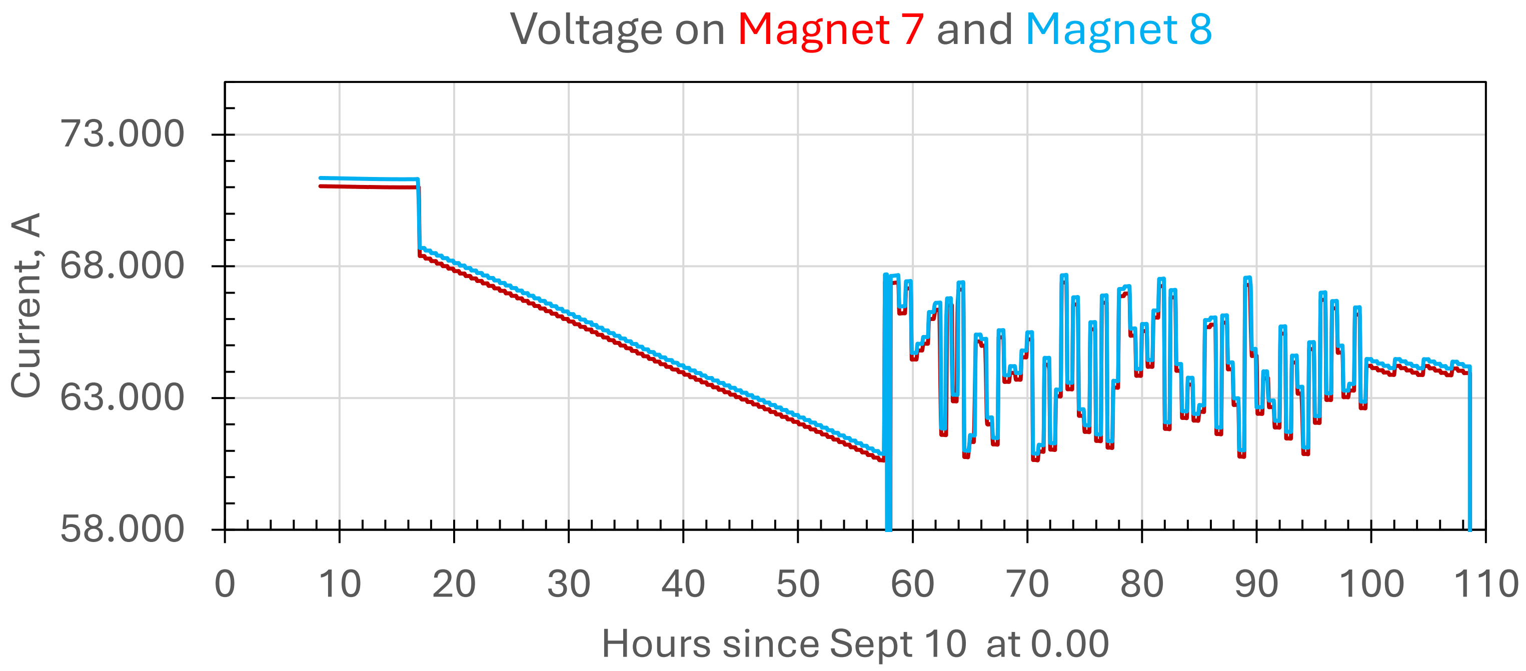


3D CHIP magnetometer on box 8



Current and Voltage on Magnet 7 & 8



# ROI background comparison 2026 vs 2025

| Run # | 142244 (2025) | Scan 2 (2026) |
|---|---|---|
| GPM | 93,600 / s | ~88,000 / s |
| All Detector | 13,011 / 30’ | ~ 8,200 / 30’ |
| ROI | 6,102 /30’ | 768 / 30’ |
| Comment | Typical run | Typical run |

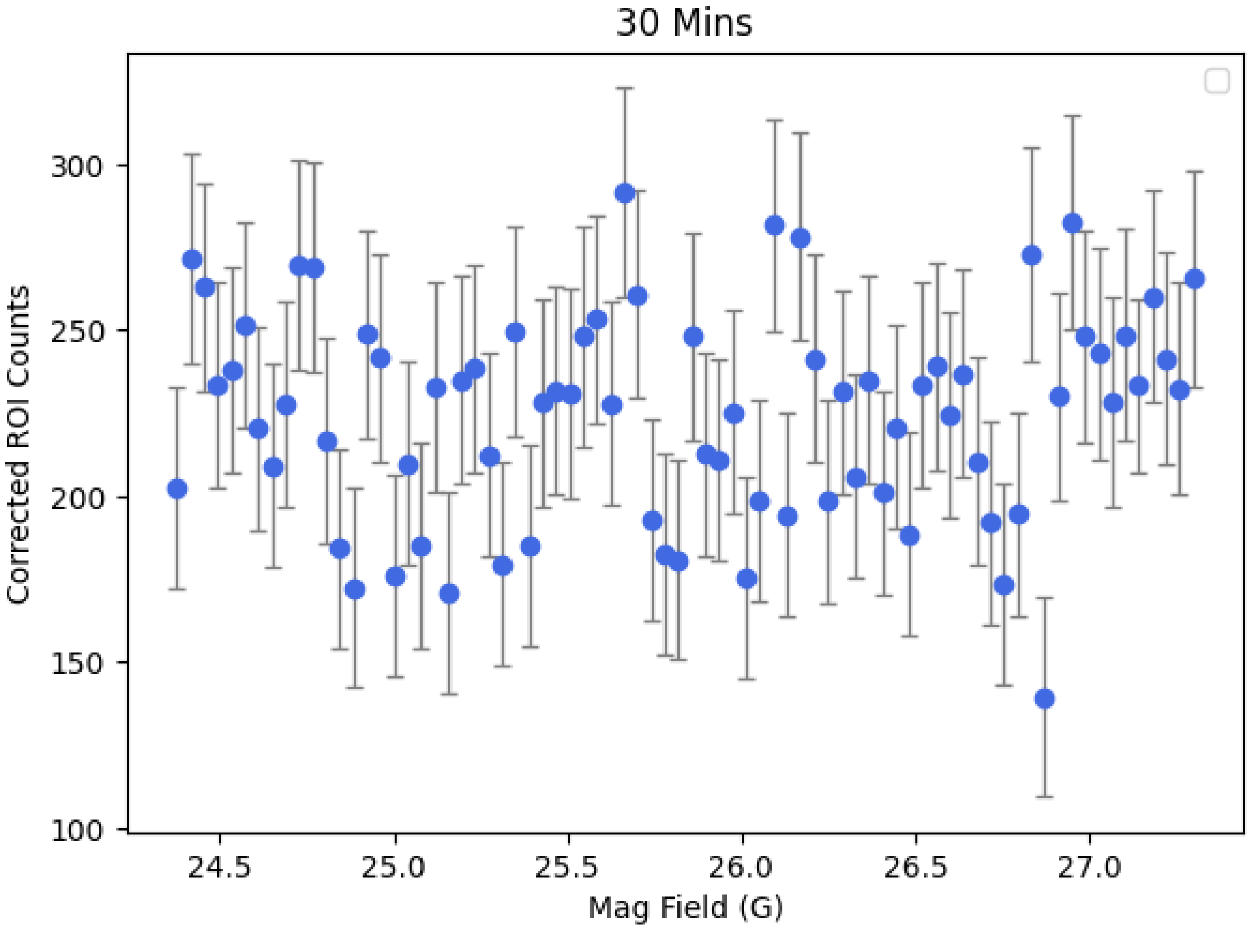
For ROI (30 cm x 36 cm) background is better by ~ 8 times

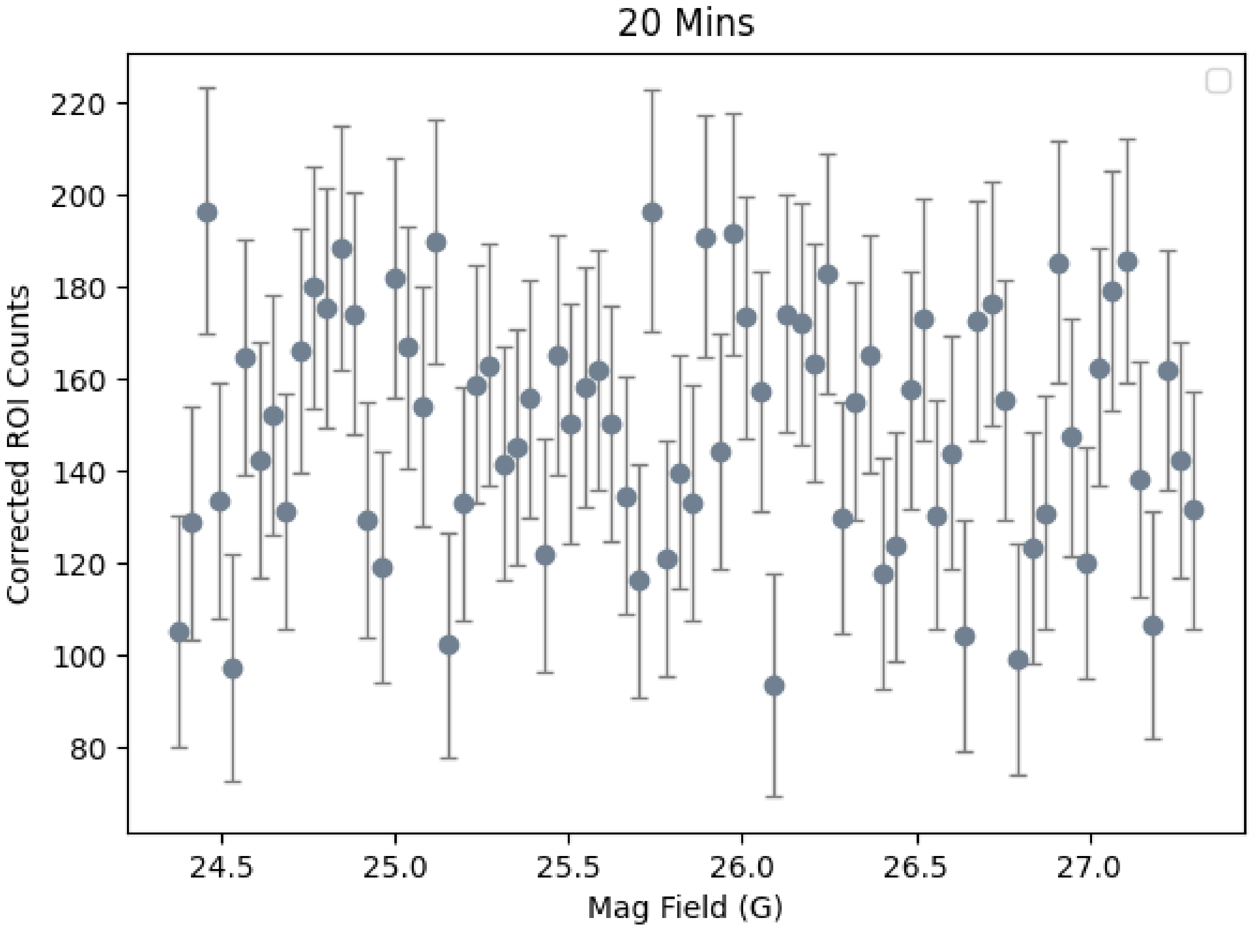
# Summer Work and Results

Alina Moore – ORNL Meeting 9/18/2026

# 2025 Experimental data

Observed Ci




* Our expected peak position is 25.896 G

# What goes into experimental data?

- Correction for intensity variation (found last year) applied due to slight change over time

$$Corrected\ Counts = \frac{C_{x,i}}{\left(\frac{GPMCounts_i}{ReferenceGPMCounts_x}\right)}$$

- Rescaled background by area ratio to subtract it from the ROI counts
  - See reference slides!!!

GPM relative intensity correction with ref. run **253** for 30-min series
GPM relative intensity correction with ref. run **346** for 20-min series
ROI 30 x 36 cm$^2$ with fast $n$ peak removed area 13.4 x 13 cm$^2$
ROI area 905.8 cm$^2$ ; ROI efficiency 90.15%
ROB 94 x 96 cm$^2$ - dead rim 5 cm around ROI 40 x 46 cm$^2$
ROB area 7376 cm$^2$, with $A_{ROI}/A_{ROB} = 0.1228$
Corrected counts in ROI :

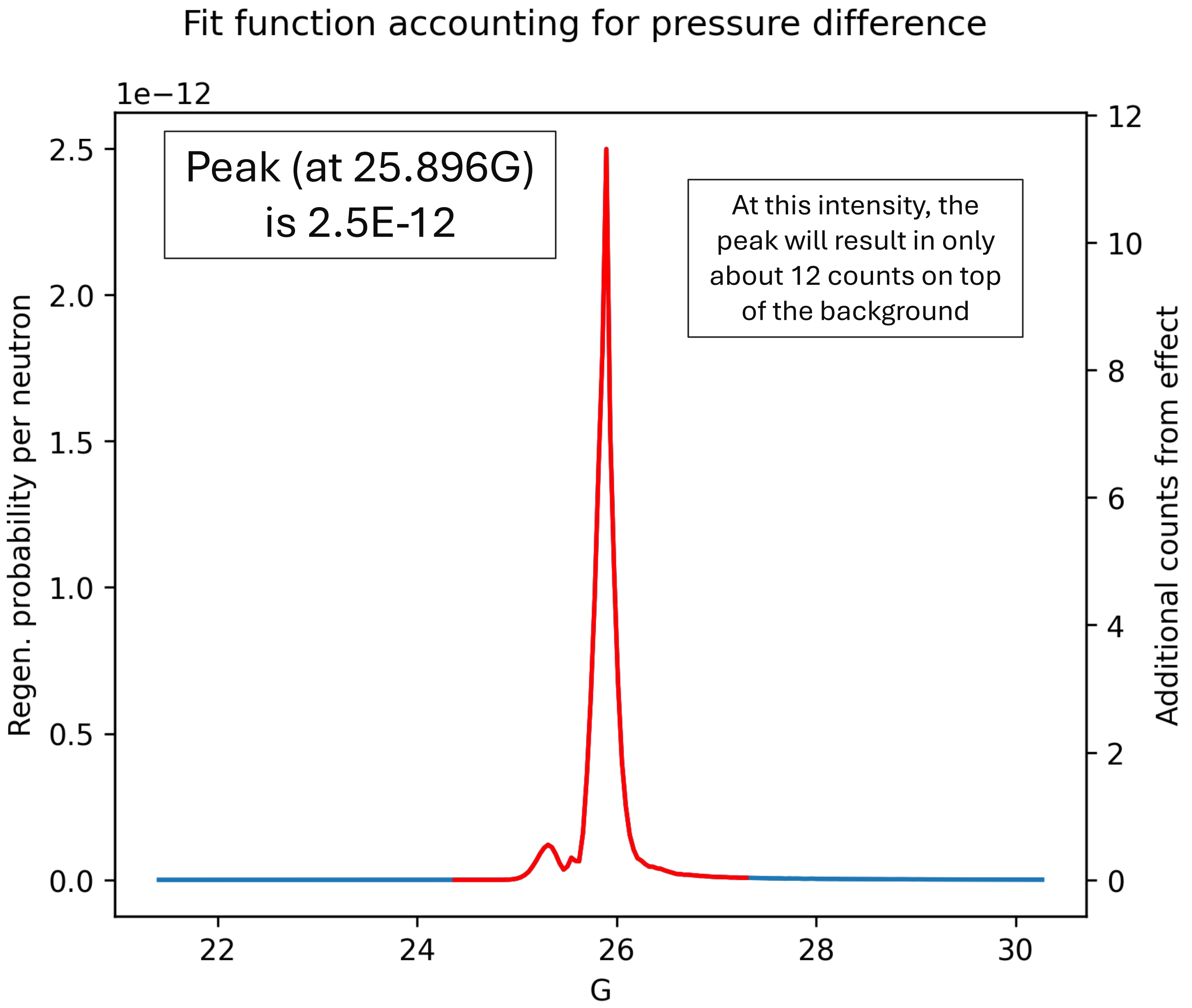
$$C_{corr} = C_{ROI} - C_{ROB} \cdot \frac{A_{ROI}}{A_{ROB}}$$

# Fit functions + explanation

- The fit function used accounts for lower sensitivity from the pressure difference during the experiment
- Corresponding to k = 5E-6

- $\delta_m$ (mass difference between n and n') is not included, will have to be additional parameter

- Given in regeneration prob. per neutron, and multiplication by intensity gives the expected counts from effect
  - This is not larger than error of each run's counts



# Fit functions + explanation continued

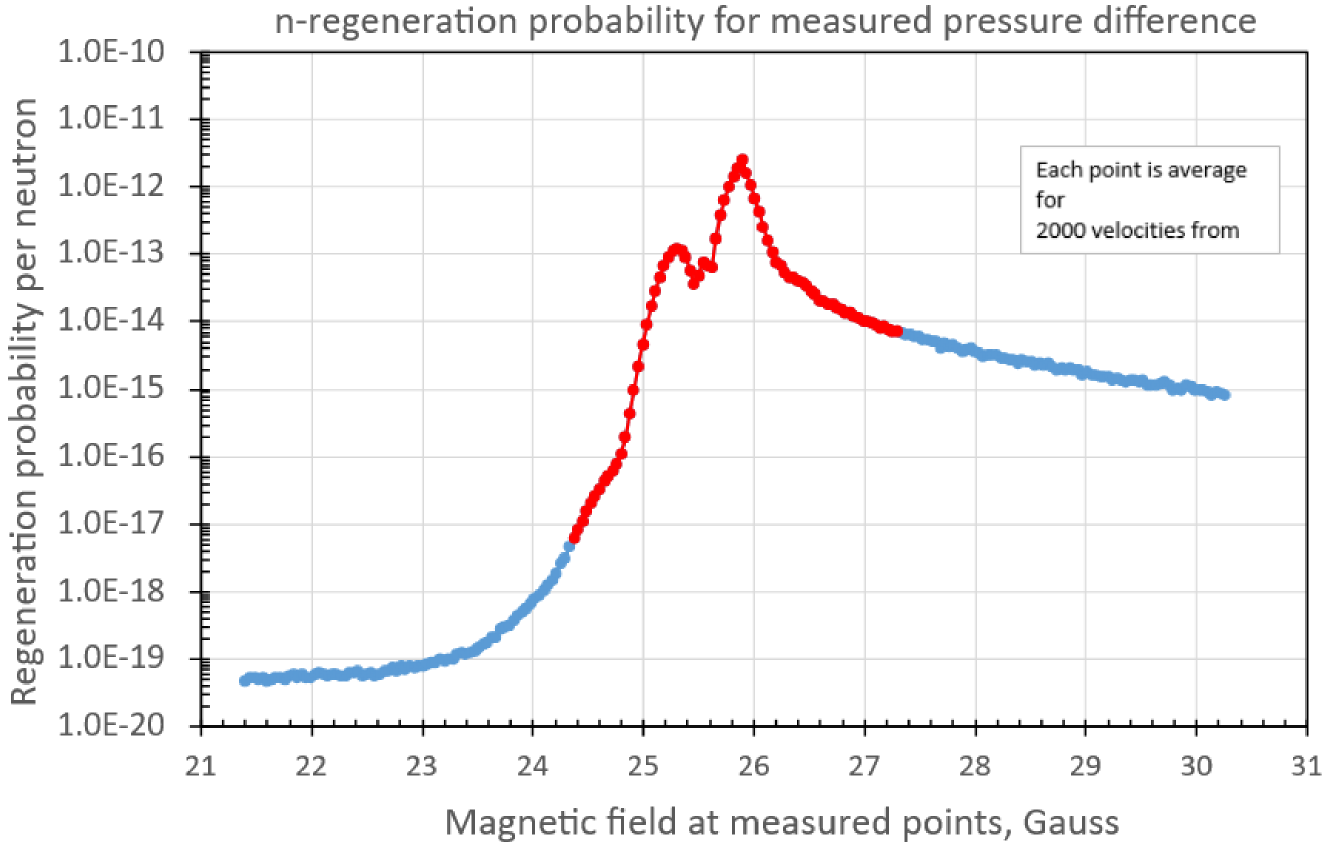
For all fits, the model is

$$aP(N) + B$$

- a is the amplitude of the effect and is proportional to $\kappa^4$.
- P(N) is the function of regeneration
  - When multiplied by intensity, it's # of additional counts from effect
  - Probability for each magnetic field value
- B is the constant background

- Function tails are extended so we can try shifting the peak to be at each point in our magnetic field range

**Log scale view of fit function**



# Context for Summer Work

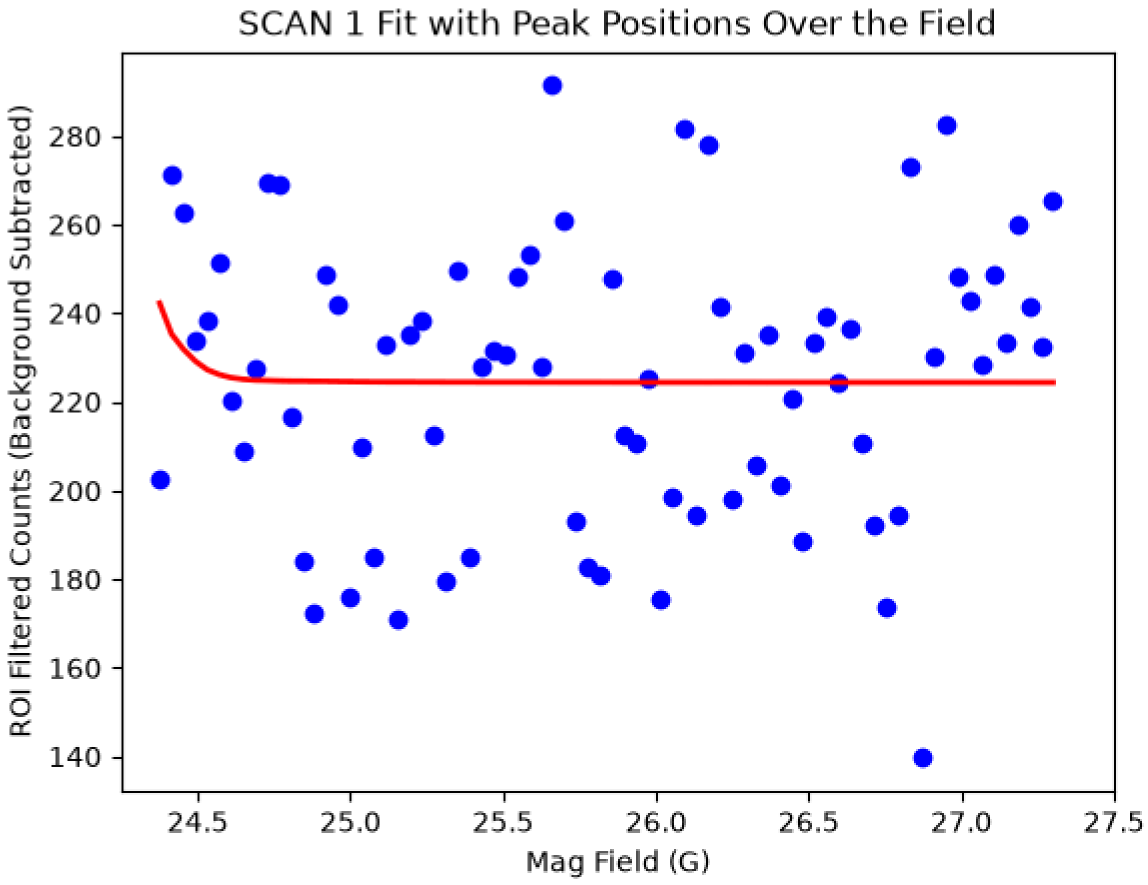
Calculated intensity:  4.59E12

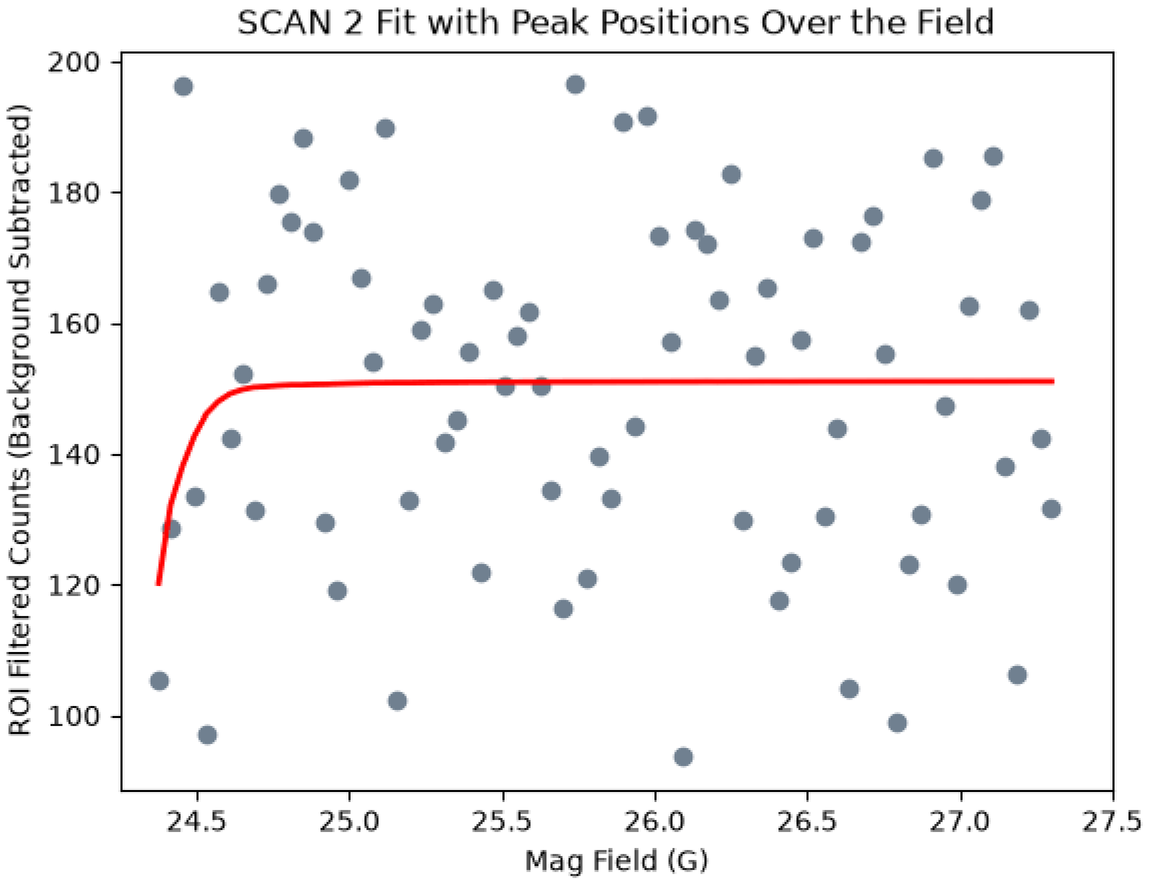
- Includes correction factors from detector and its hardware

- There have been 3 main fitting tasks
  - Curve fit to experimental data
    - Try it for the peak fixed at each position in the magnetic field
  - Curve fit to pure background (generated using the B parameter estimate from part 1)
  - Curve fit to generated distributions with effect sitting on top of background
    - For calibration only
    - Compare with real data

- 95% Feldman-Cousins confidence intervals for the first two tasks

# Animation to show fixing the peak through our field range



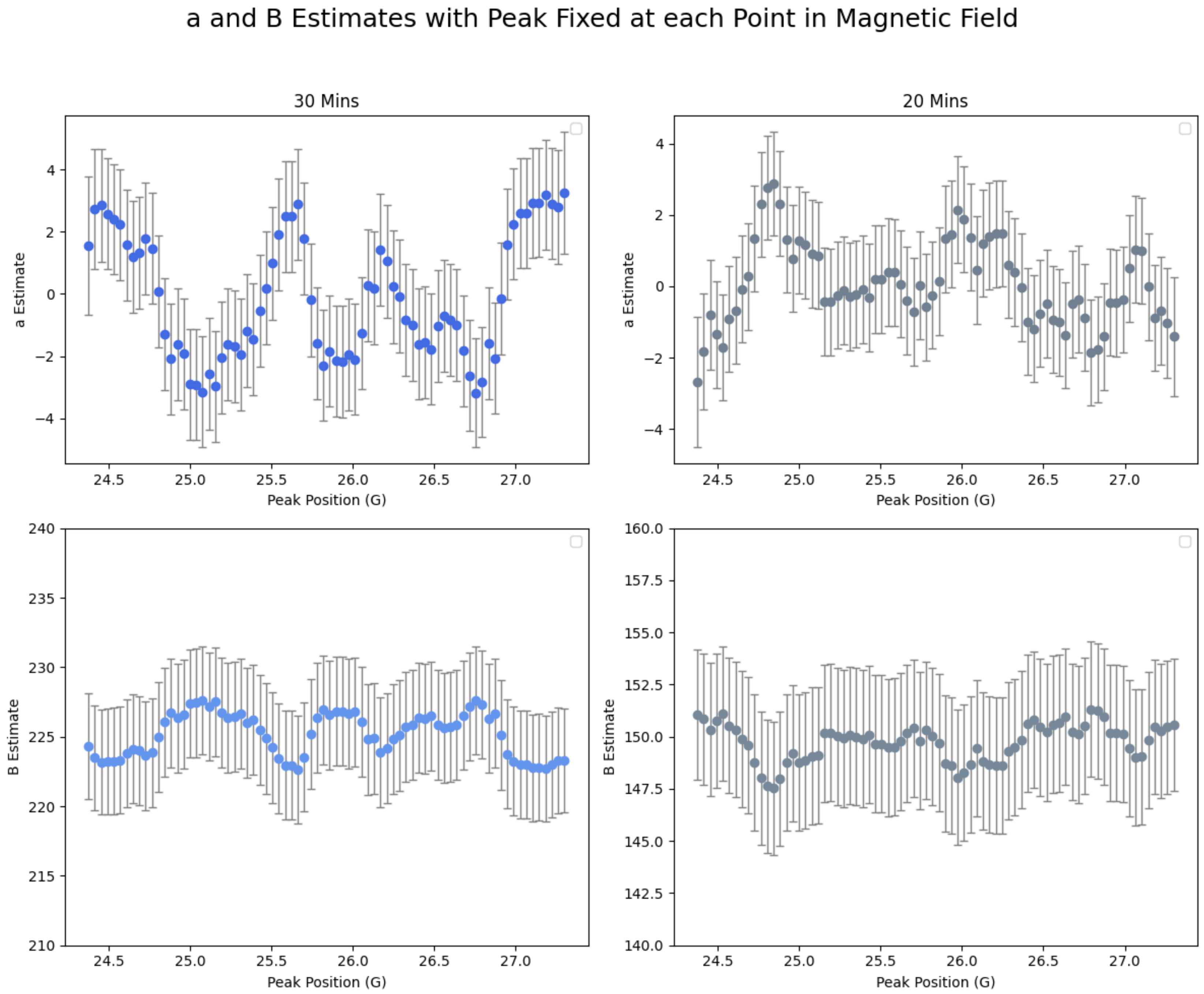




The fit can estimate a negative effect even though we assume a is not negative in real life

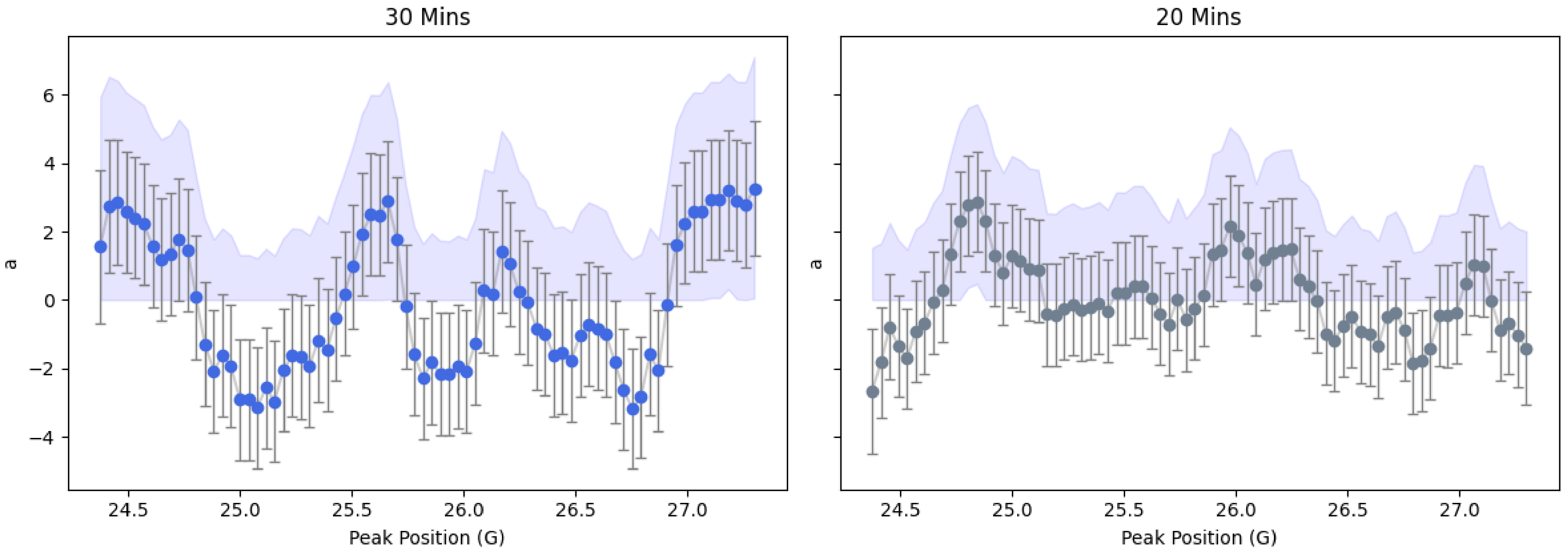
Shifting the fit function to fix the peak at each point and doing curve fitting
- 'what if the peak was here?' x76

B estimates vary within about 5 and are realistic for our measured points

A and B estimates are inversely related to each other
- In real life BG should be independent
- Errors come from fit's correlation matrix



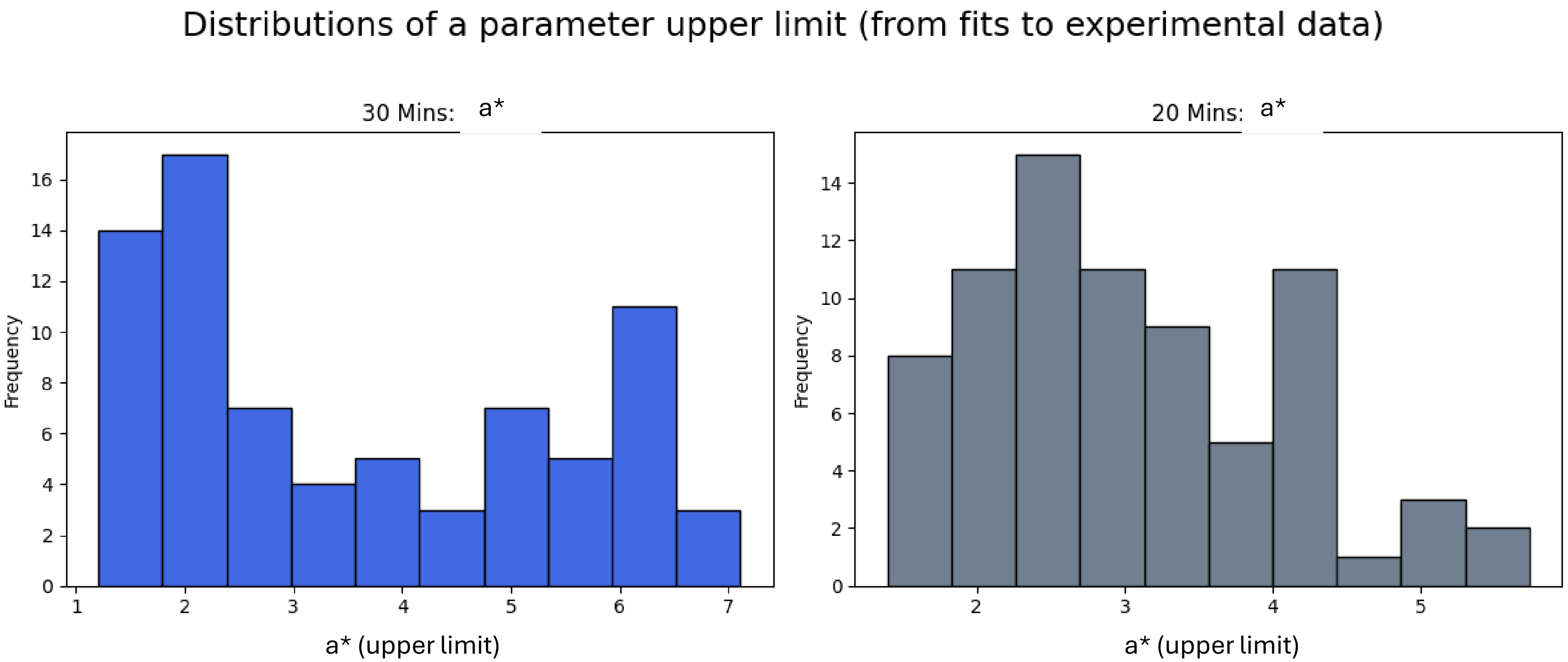
# 95% FC Intervals (a)



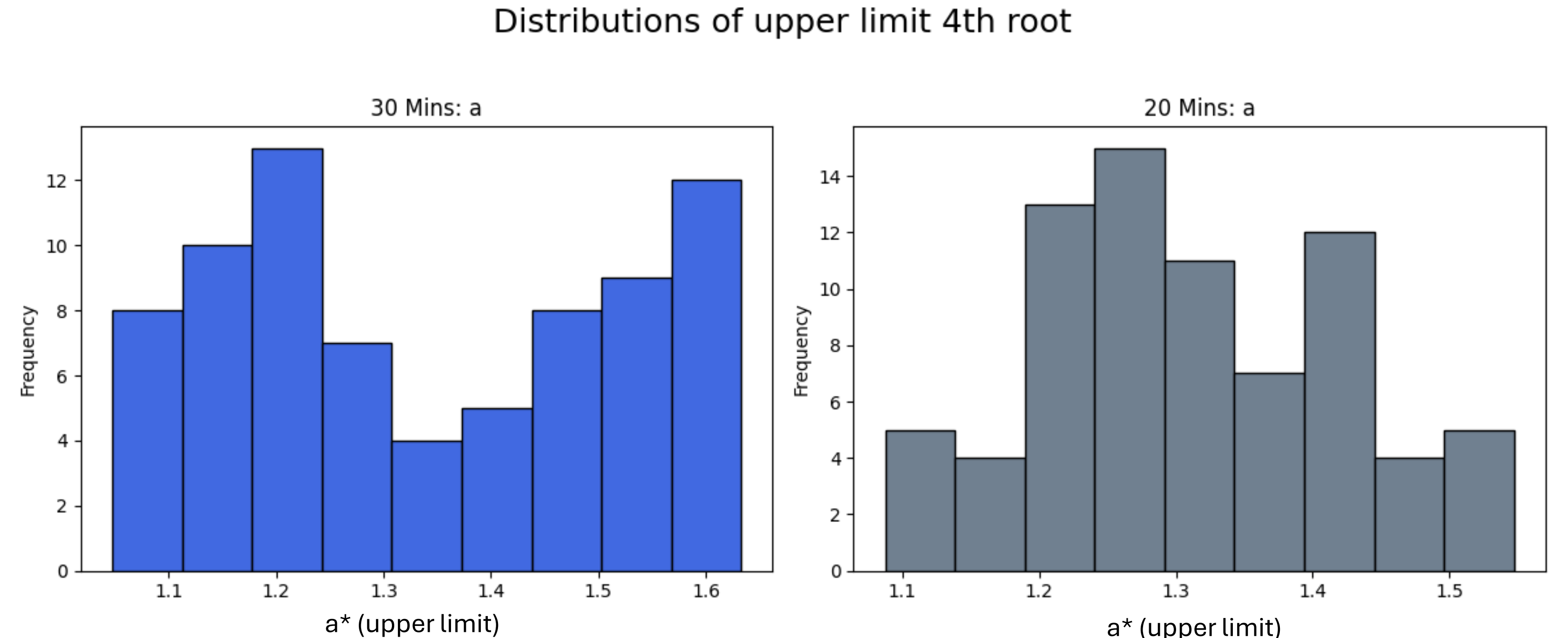

- Using FC limits for the gaussian bounded at 0 case (table 10 in the paper)
- $x_0 = \frac{aEstimate}{aEstimateError}$ where aEstimateError is given in the correlation matrix from the fit
- Rescale by aEstimateError to get the interval limits back in terms of a (shown in plot)

- Comes from the real data, one experiment for each length of time

- Histograms built from 76 a estimates (result from each fit)




- Using the confidence interval upper limits removes values for a negative effect that we assume is impossible



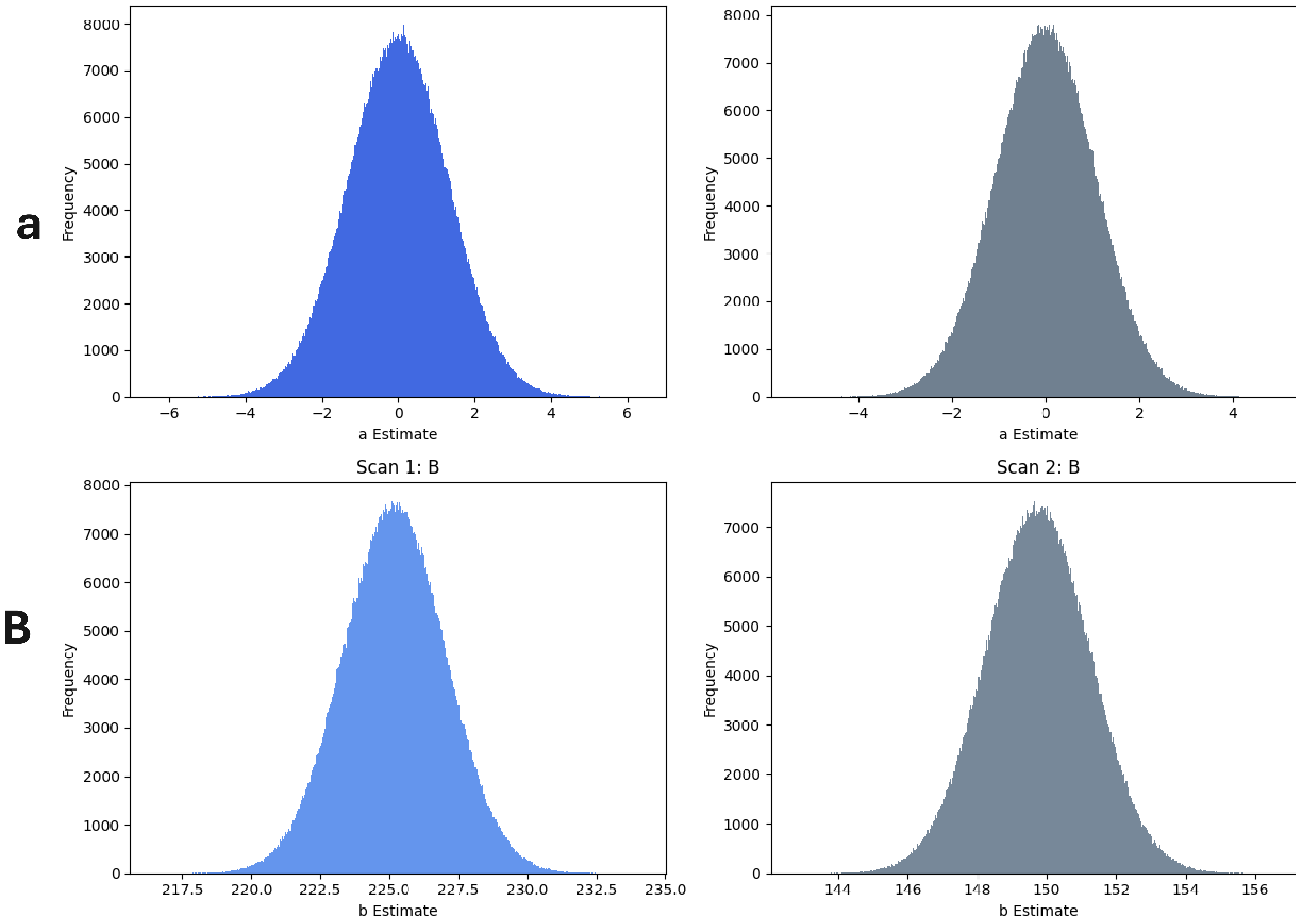
# Simulating pure background

- Generate 1 mil experiments (of 76 runs, same as the real one) with only poisson (approximately normal) distributed background
  - Use $\bar{B}$ for $\mu$
  - $\sqrt{\bar{B}}$ for $\sigma$
- No effect added
- Repeat the curve fitting procedure on each experiment
  - These should be sets of 76 randomly generated values from the background distribution
- Use same method for finding each estimate's 95% confidence intervals

1,000,000 iterations

# Results from simulation: what you'd expect

a centered around 0 and B around $\bar{B}$



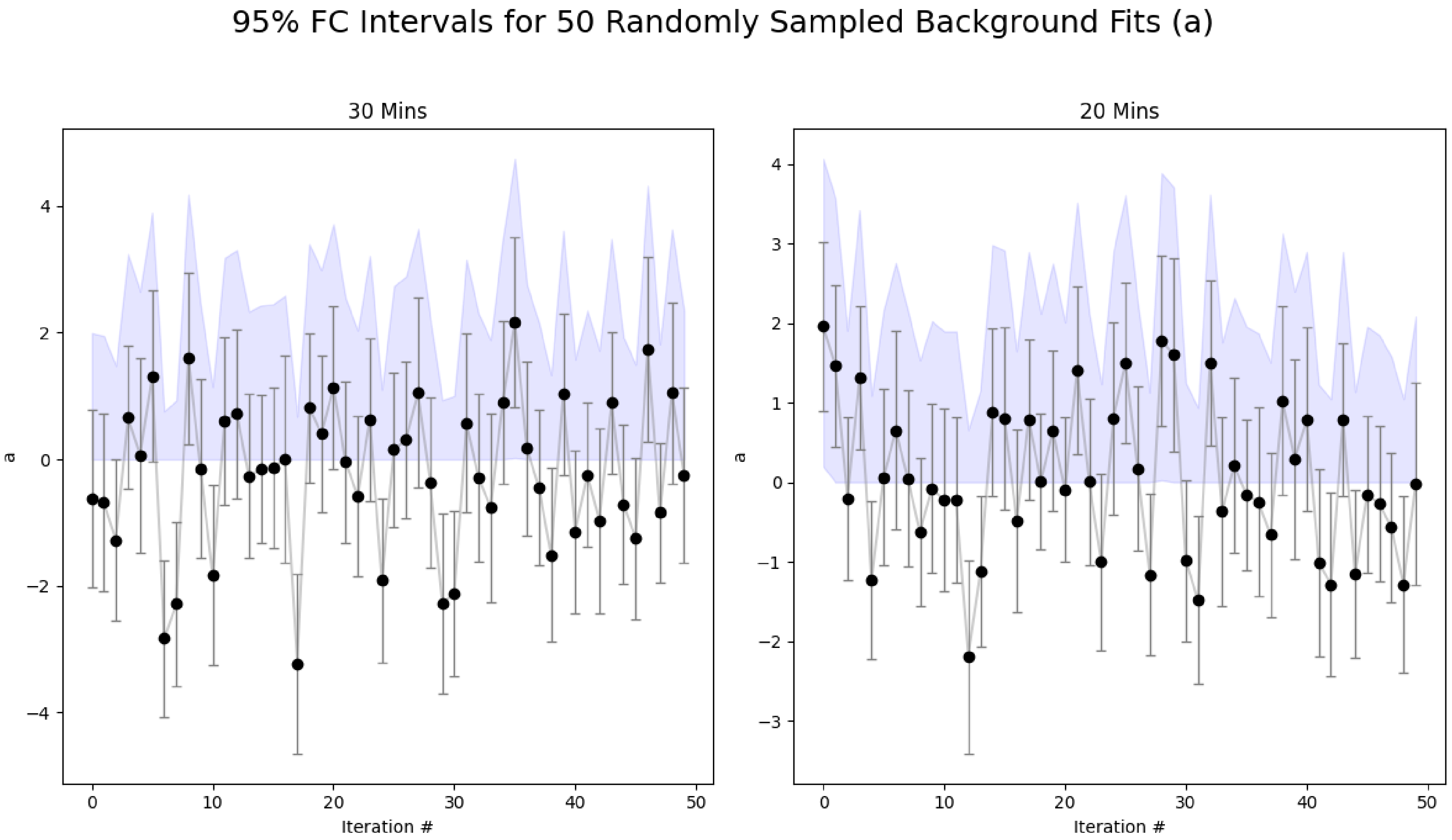
Example estimations:

- Plotting 1mil points would not be useful
- Randomly picked 50 to show in the plots with FC intervals

- Here, the distribution the estimates come from is created, so

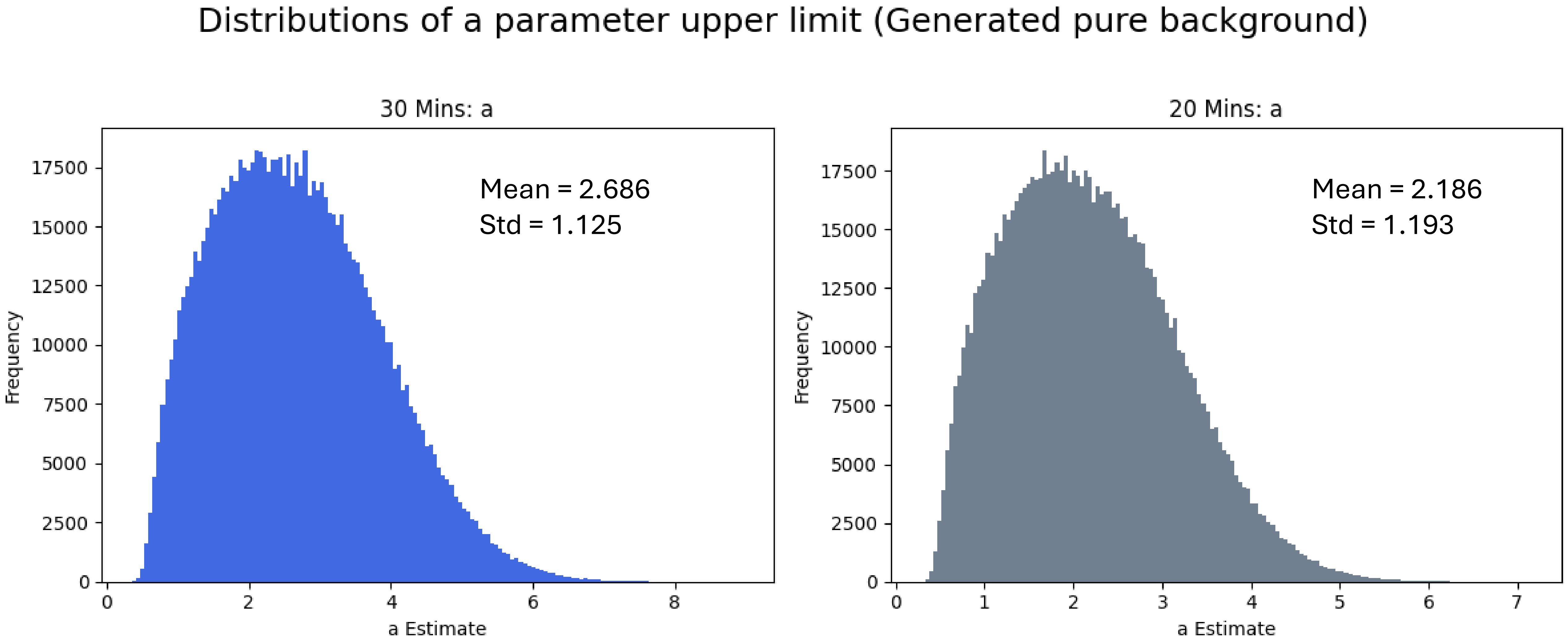
$$x_0 = \frac{aEstimate}{\sigma}$$

Where $\sigma$ is the standard deviation of the distribution of 1mil a estimates



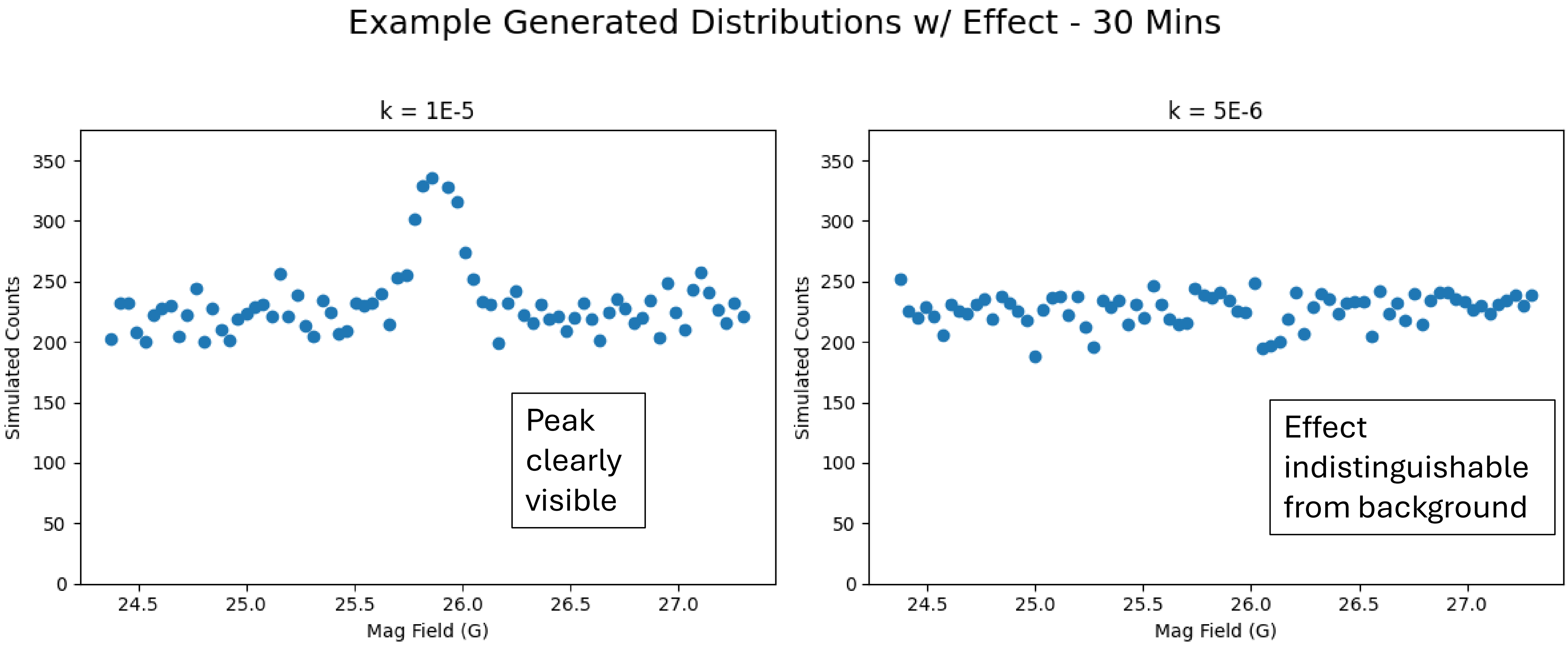

*multiply the interval limits by $\sigma$ to get them in terms of a

# Distributions of upper FC limits (a*) for background



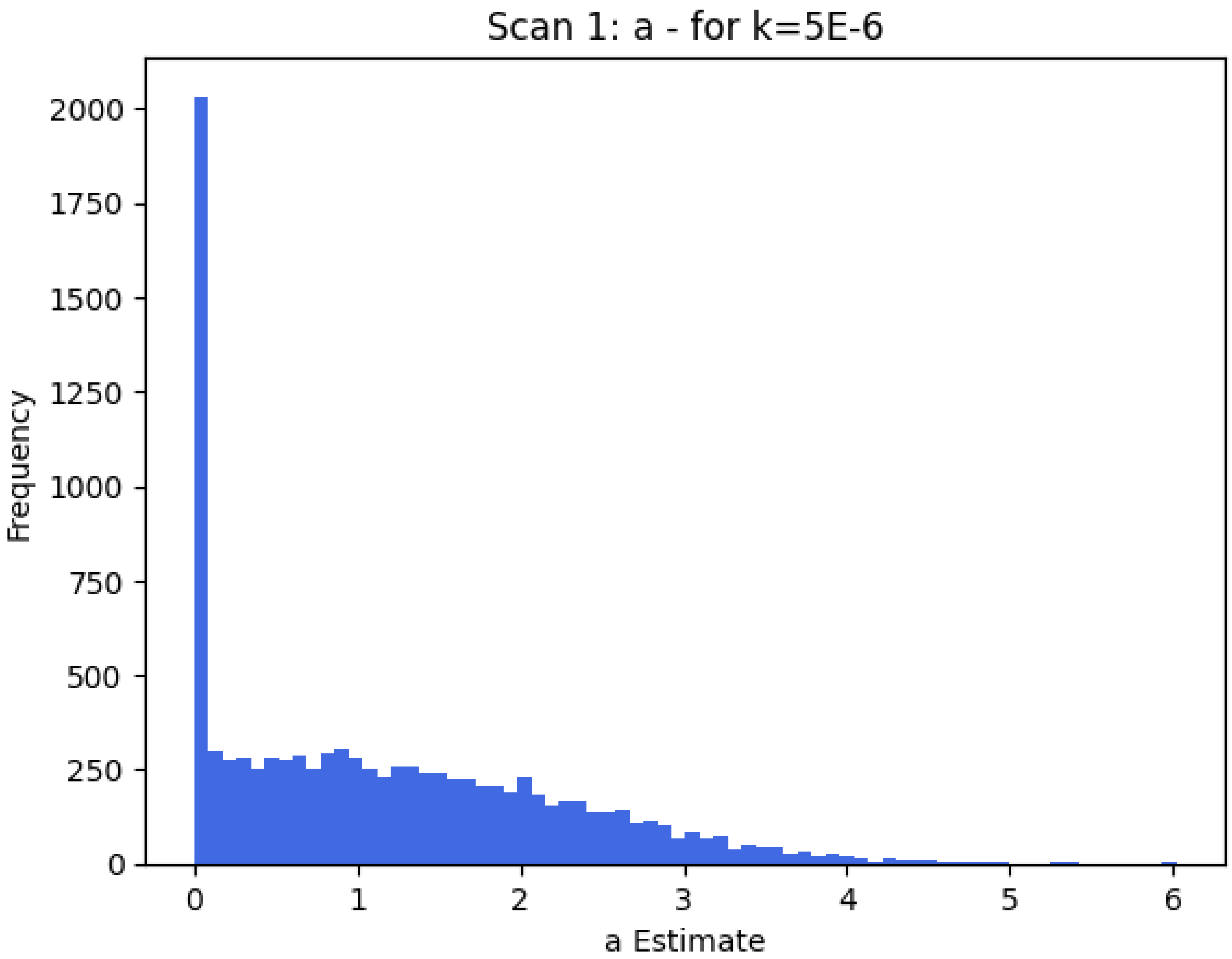
# Generated distribution with effect

- Meant for calibration of a parameter (how does it relate to k?)
- Even though we assume a 5E-6 effect, use 1E-5 for this case only for clarity.
- Effect is added on top of the background like usual

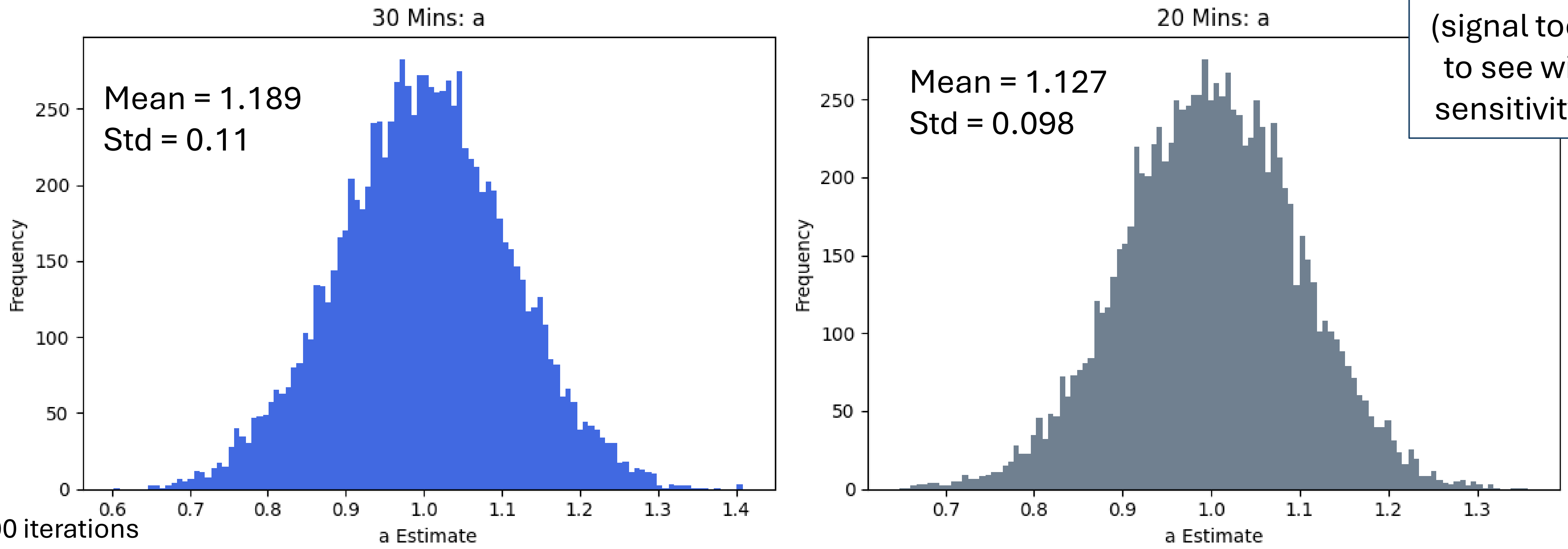


# Result for fit with function for k=5E-6 (why we won't use it)

- Points less than 0 are forced to be 0 due to the boundary set for the fit
- No confidence intervals because the error can't be estimated (consequence of fitting at a single data point)
- We fit only with the peak point for calibration because A is related to it



# Distributions of a parameter for Generated Distributions with Peak

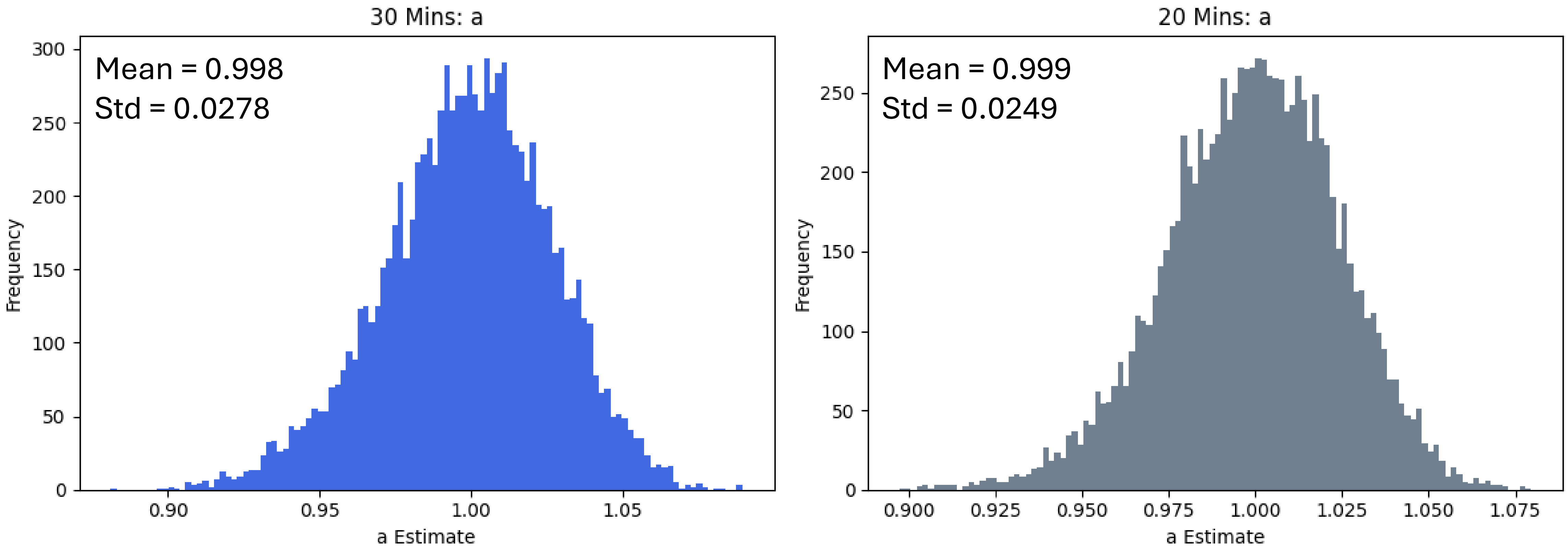



For if k = 1E-5 instead of 5E-6 (signal too small to see with our sensitivity level)

10,000 iterations

- Had to force a > 0 for this to run because it is fit only with the peak point
  - Single point curve fits have INF correlation matrices
- a is proportional to $\kappa^4$, so $\kappa = c\sqrt[4]{a}$ where c is some constant.
- These effects are all positive due to the higher sensitivity. No FC limit needed for cutting negatives

## Distributions of a parameter for Generated Distributions with Peak (1/4 root)




Histogram of the 4th root of the values from the distributions on previous slide

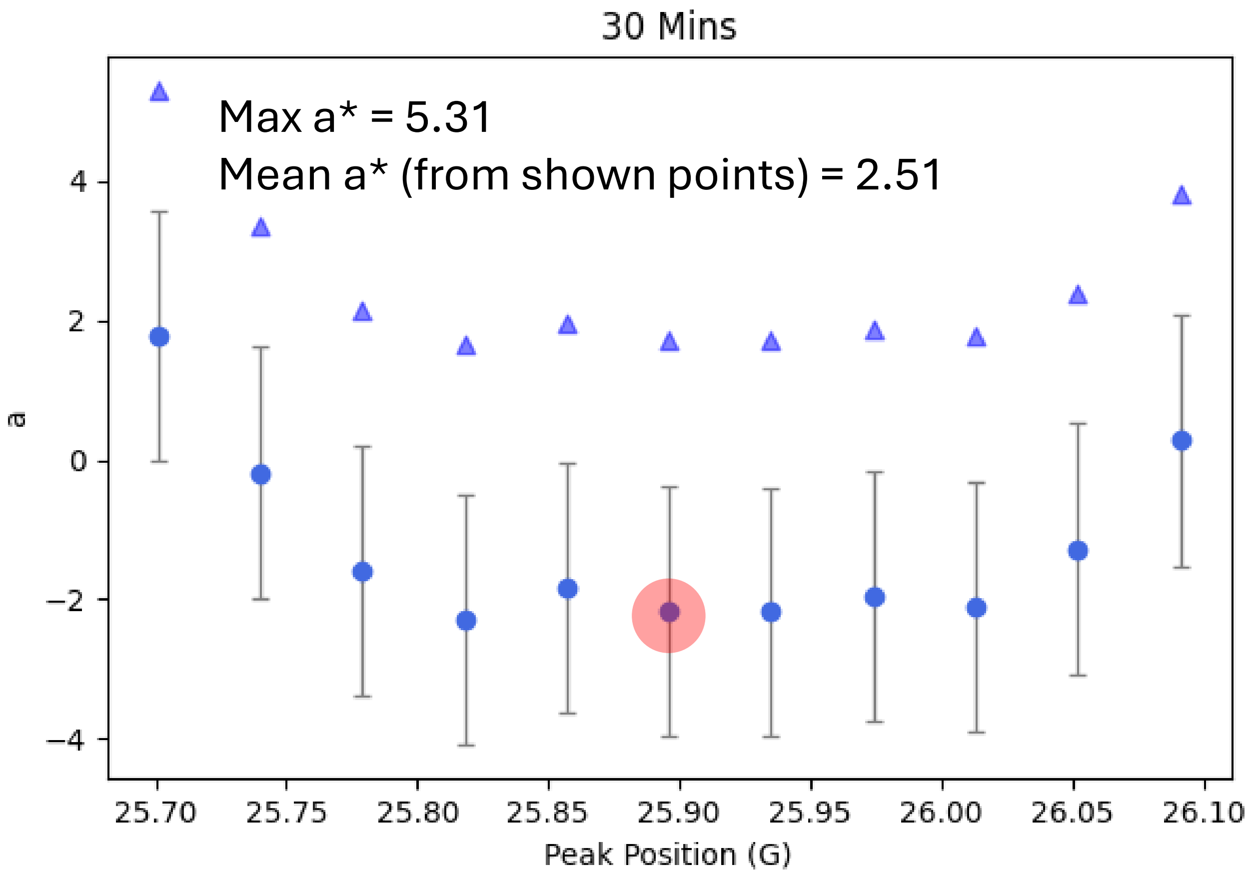
Finding $a_c$ (a for calibration)

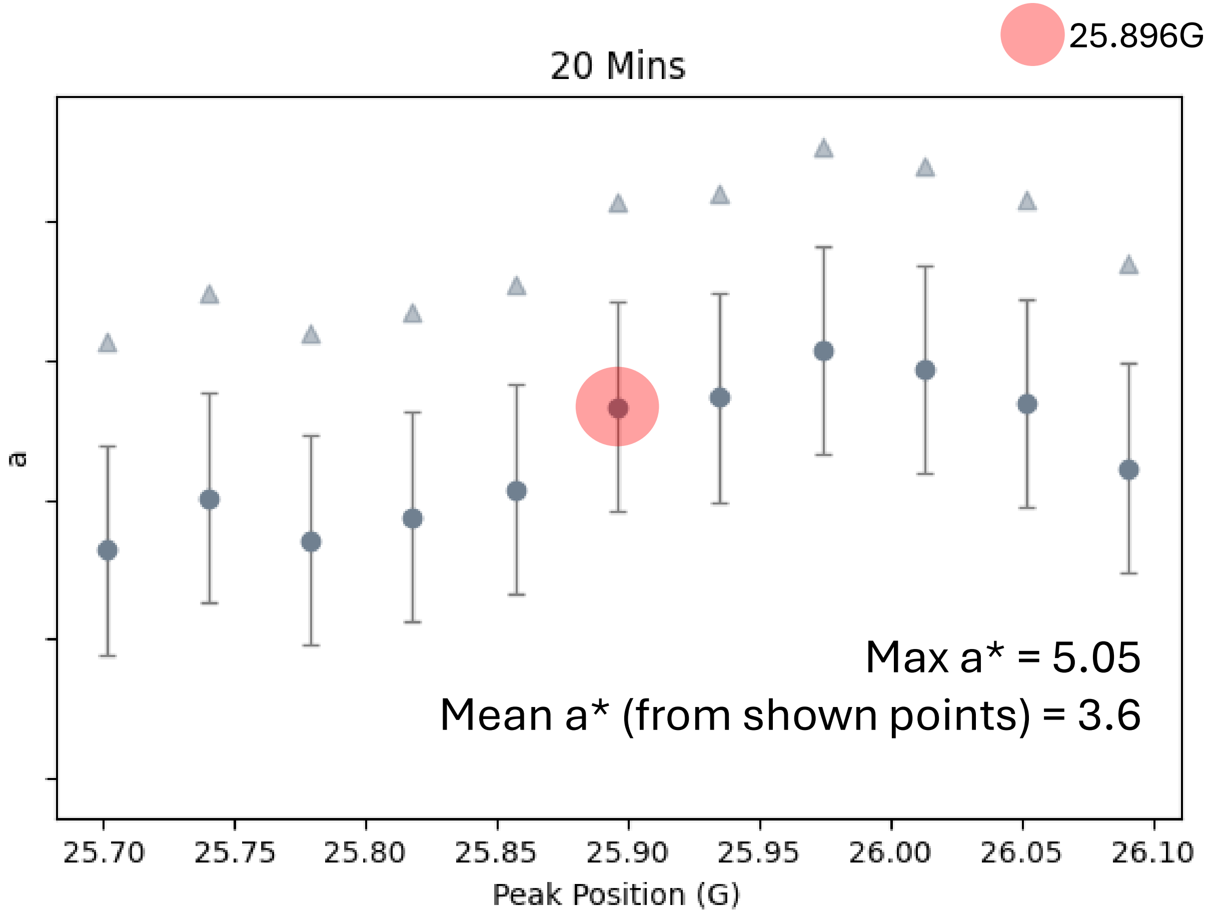
# Finding upper limit of k from our data sets & calculations

**Notation:**

- a: estimate of a parameter
- $\delta_a$: error of a estimate from correlation matrix from fits to experimental data
- a*: upper limit of Feldman-Cousins confidence interval for a given a estimate
- $\kappa = 5E - 6 * \sqrt[4]{a^*}$ in all cases but for calibration

# a and a* around the expected peak position for fits to experimental data


$\sqrt[4]{\max(a^*)} = \sqrt[4]{5.31} = 1.518 * 5\times 10^{-6} =$ $\mathbf{7.59\times 10^{-6}}$

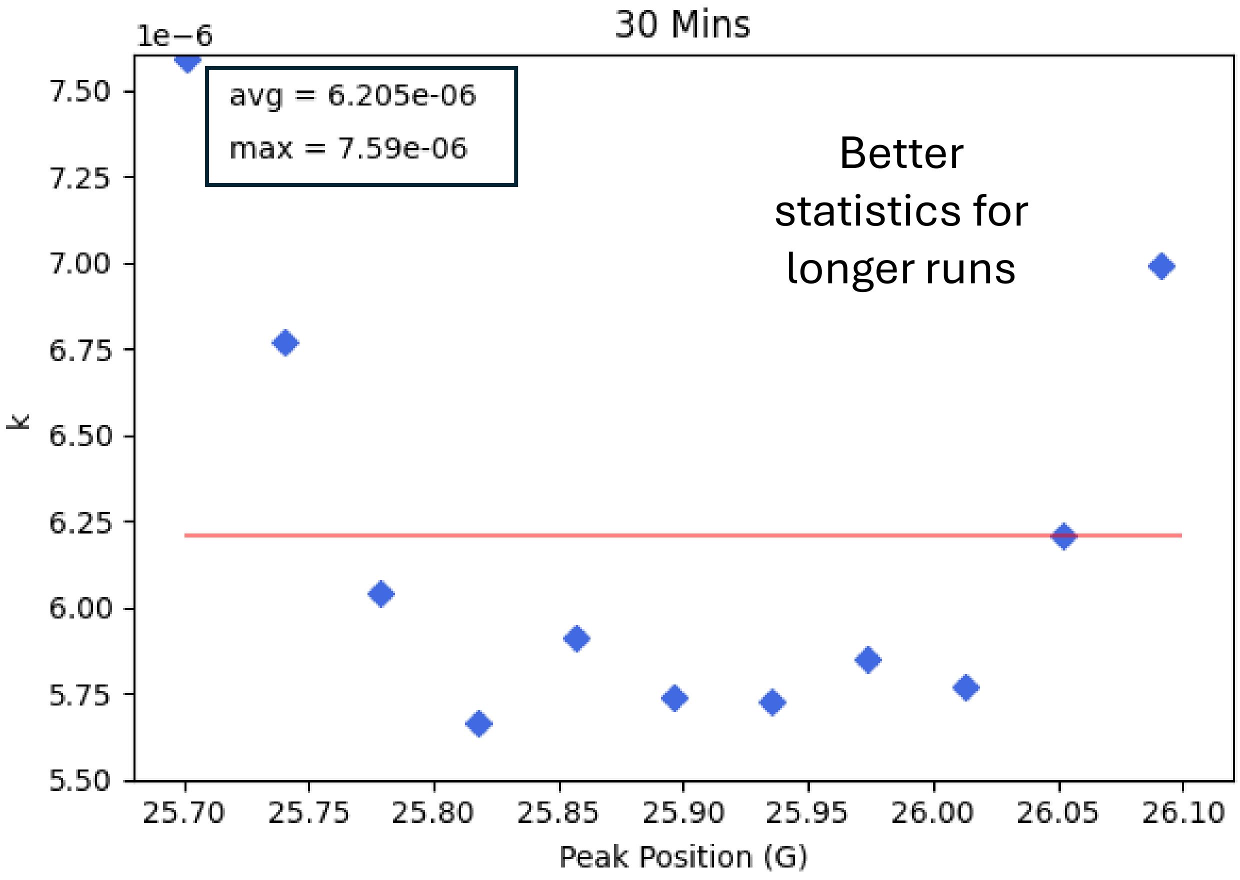
$\sqrt[4]{\text{mean}(a^*)} = \sqrt[4]{2.51} = 1.259 * 5\times 10^{-6} = 6.295\times 10^{-6}$

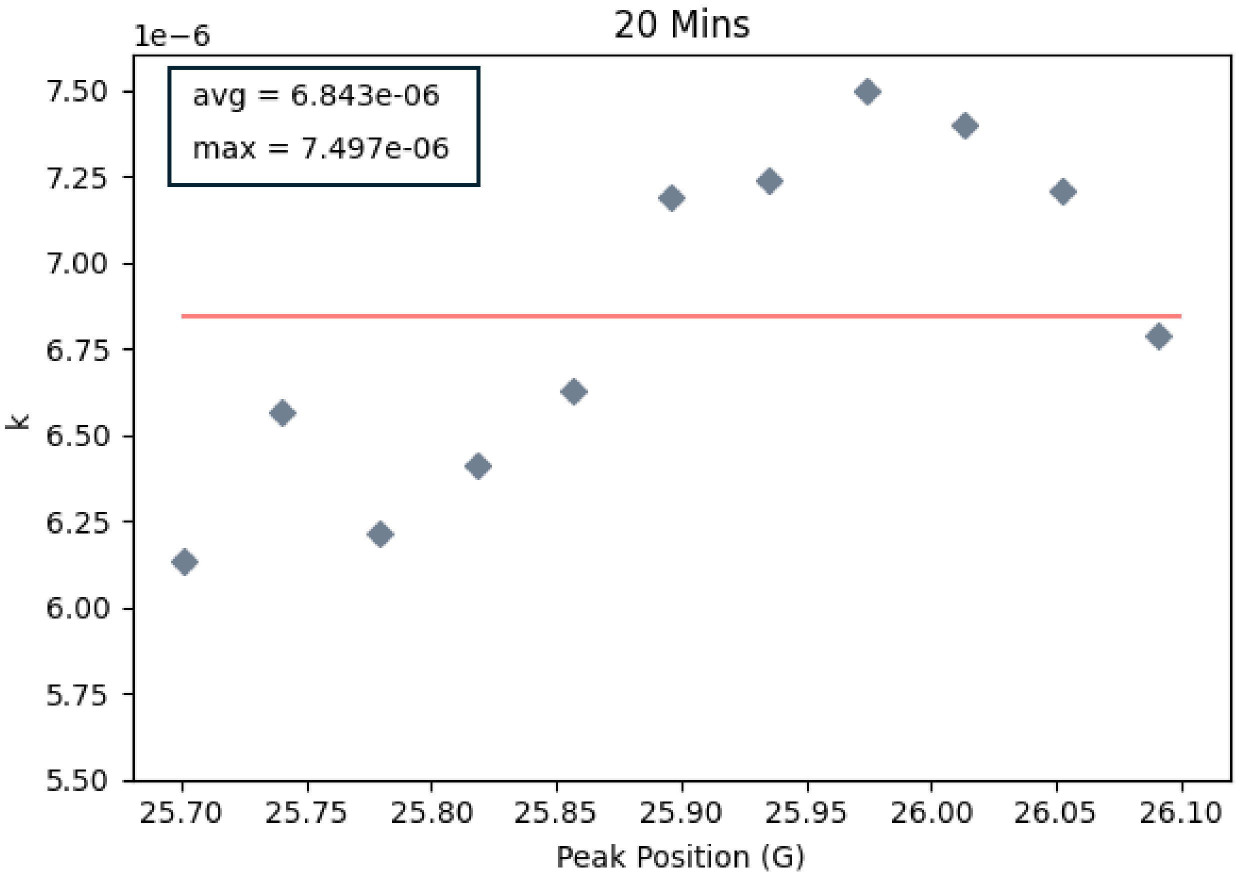
$\sqrt[4]{\max(a^*)} = \sqrt[4]{5.05} = 1.499 * 5\times 10^{-6} = 7.495\times 10^{-6}$

$\sqrt[4]{\text{mean}(a^*)} = \sqrt[4]{3.6} = 1.383 * 5\times 10^{-6} =$ $\mathbf{6.915\times 10^{-6}}$

# Upper FC Limits in terms of k

From experimental data around 25.896 G. k = 5E-6($\sqrt[4]{a*}$)




- In ITPS proposal, our experiment's goal is 5E-6 was the level of $\kappa$ to reach. Came close to original goal but pressure difference during the run lowered sensitivity
- In 2026 run, sensitivity will be improved by 81x with constant pressure and better shielding. Factor ~3 improvement in k limit. Ideally the limit will go from 6 to about 2

# Final Result From Experimental Data

**30 mins**

$\kappa = 6.205\text{E-}6$

**20 mins**

$\kappa = 6.84\text{E-}6$

# Final Results From Simulations

## Pure Generated Background (for k=5E-6)

From simulated 30 min runs

$\sqrt[4]{\text{mean}(a^*)} = \sqrt[4]{2.686} = 1.28 \ * \ 5\times 10^{-6} =$ **$6.4 \times 10^{-6}$**

From simulated 20 min runs

$\sqrt[4]{\text{mean}(a^*)} = \sqrt[4]{2.186} = 1.21 \ * \ 5\times 10^{-6} =$ **$6.08 \times 10^{-6}$**

## Generated distributions with effect (for k=1E-5)

From simulated 30 min runs

$\sqrt[4]{\text{mean}(a_c)} = \sqrt[4]{1.189} = 1.044 \ * 1\times 10^{-5} =$ **$1.044 \times 10^{-5}$**

From simulated 20 min runs

$\sqrt[4]{\text{mean}(a_c)} = \sqrt[4]{1.127} = 1.03 \ * 1\times 10^{-5} =$ **$1.03 \times 10^{-5}$**

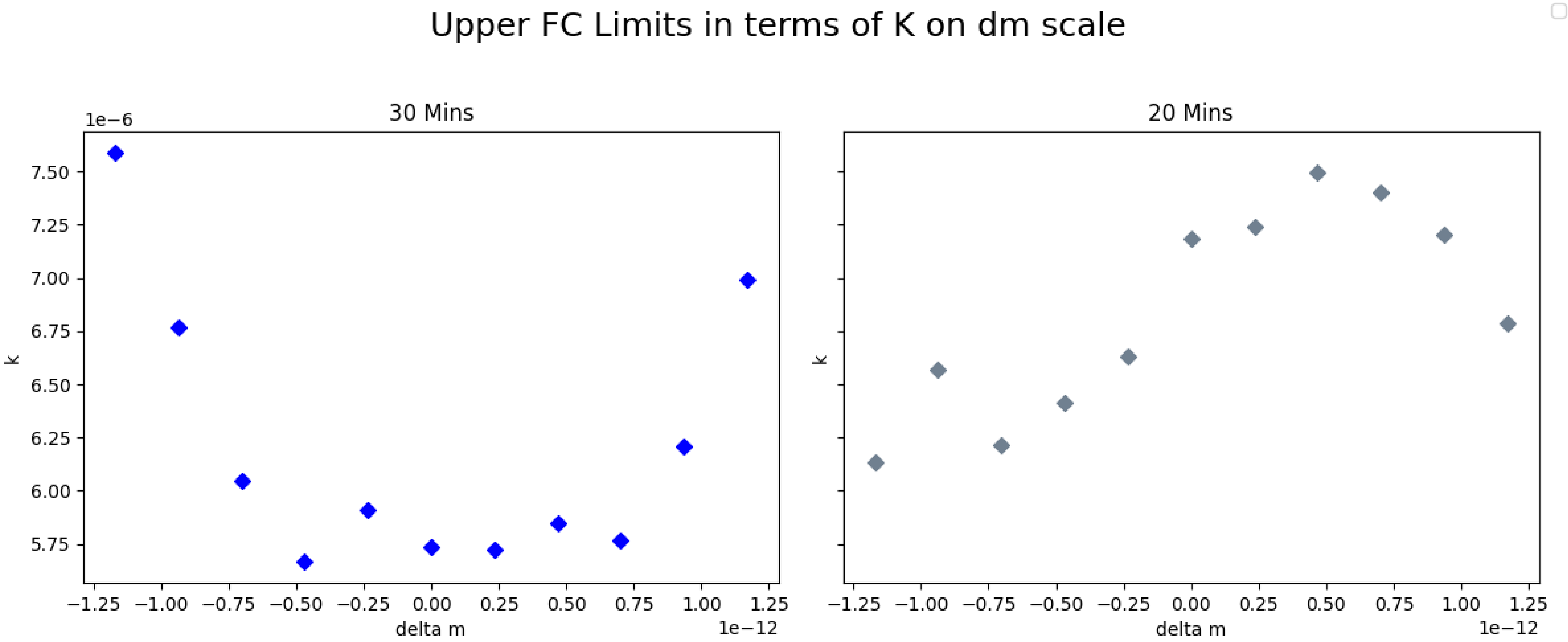
# Final $\kappa$ value table

| Source | 30 mins | 20 mins |
|---|---|---|
| Experimental | 6.205E-6 | 6.84E-6 |
| Simulated background | 6.4E-6 | 6.08E-6 |
| Simulated distribution with background (for calibration) | 1.044E-5 | 1.03E-5 |

# Additional

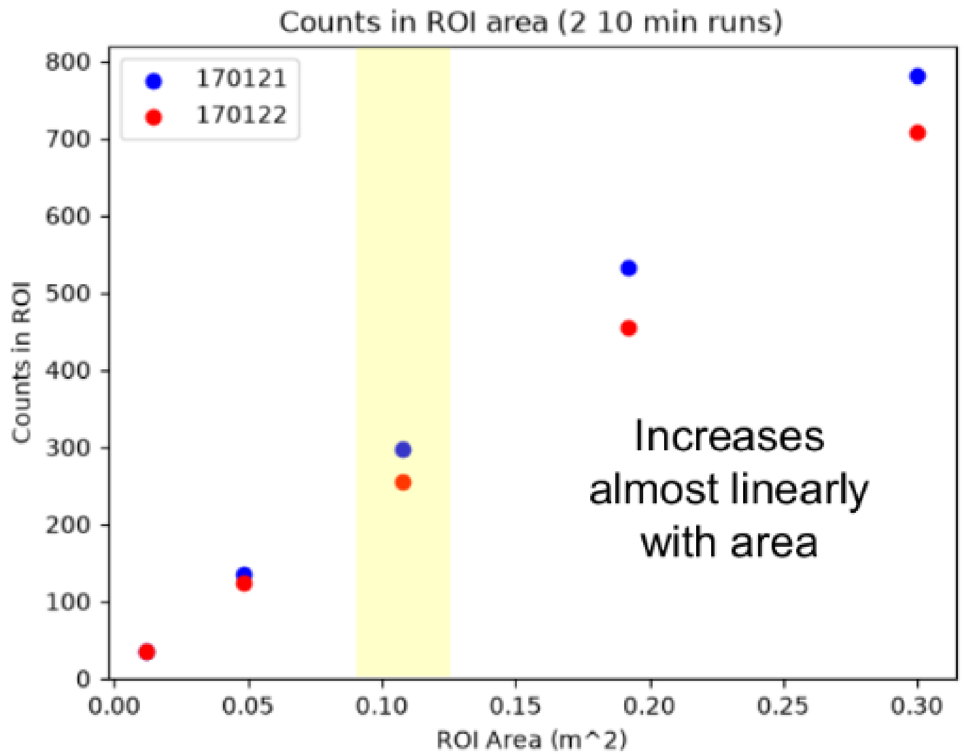
# In terms of $\delta_m$ (a different x axis)

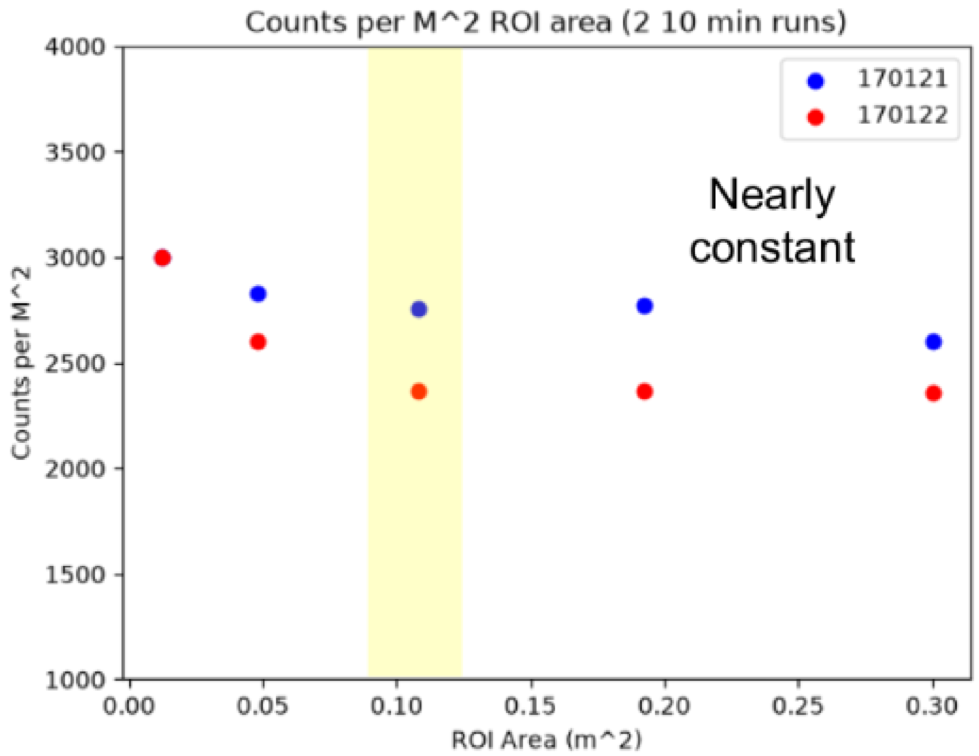
- Using the experimental data, take distance from expected peak (B in G) for each position tried. This is positive and negative around 0
- Multiply the distances by 6E-12 to get it in $\delta_m$ scale
- For a model where $\delta_m$ is another parameter, this shows that for different $\delta_m$ we set a different value of $\kappa$



# nTMM 2 BG quick analysis

- Need to add errorbars, but relationship is visible



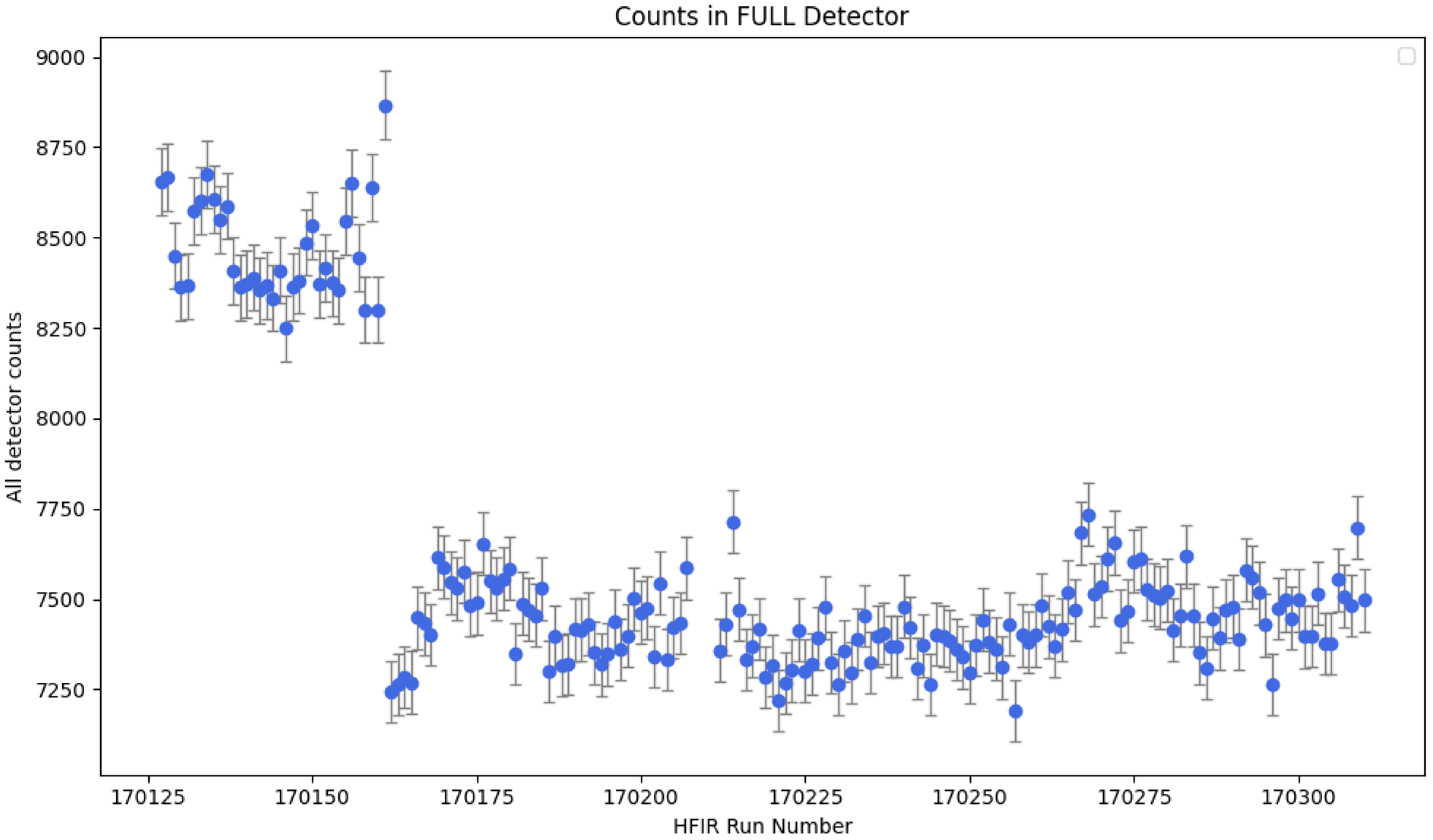




Tried 5 ROI sizes

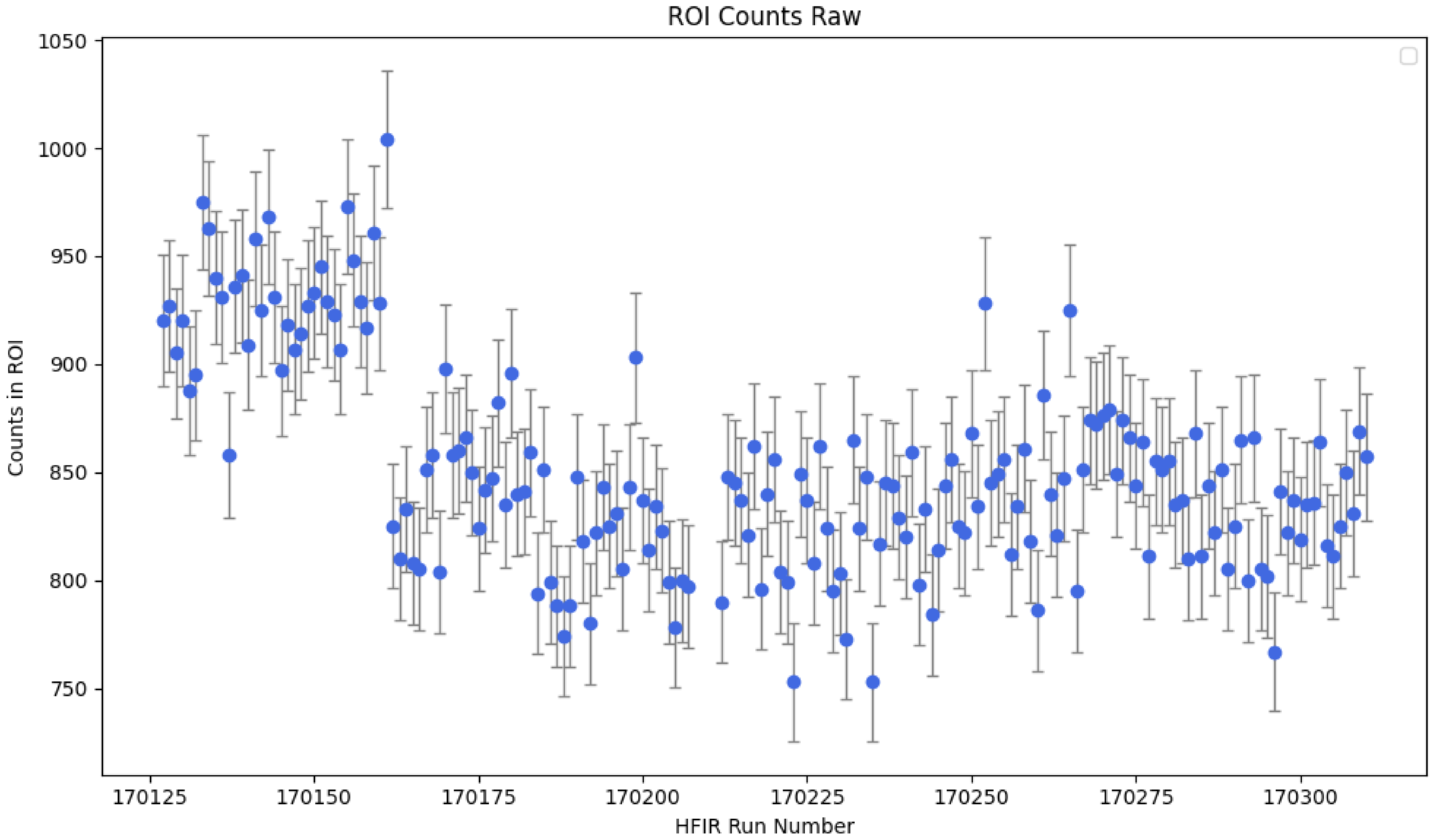
Smallest: 0.10*0.12
Small: 0.20*0.24
Real: 0.30x0.36
Big: 0.40*0.48
Biggest: 0.5*0.6

Supports that the background is uniform throughout the detector, makes subtraction from ROI counts feasible

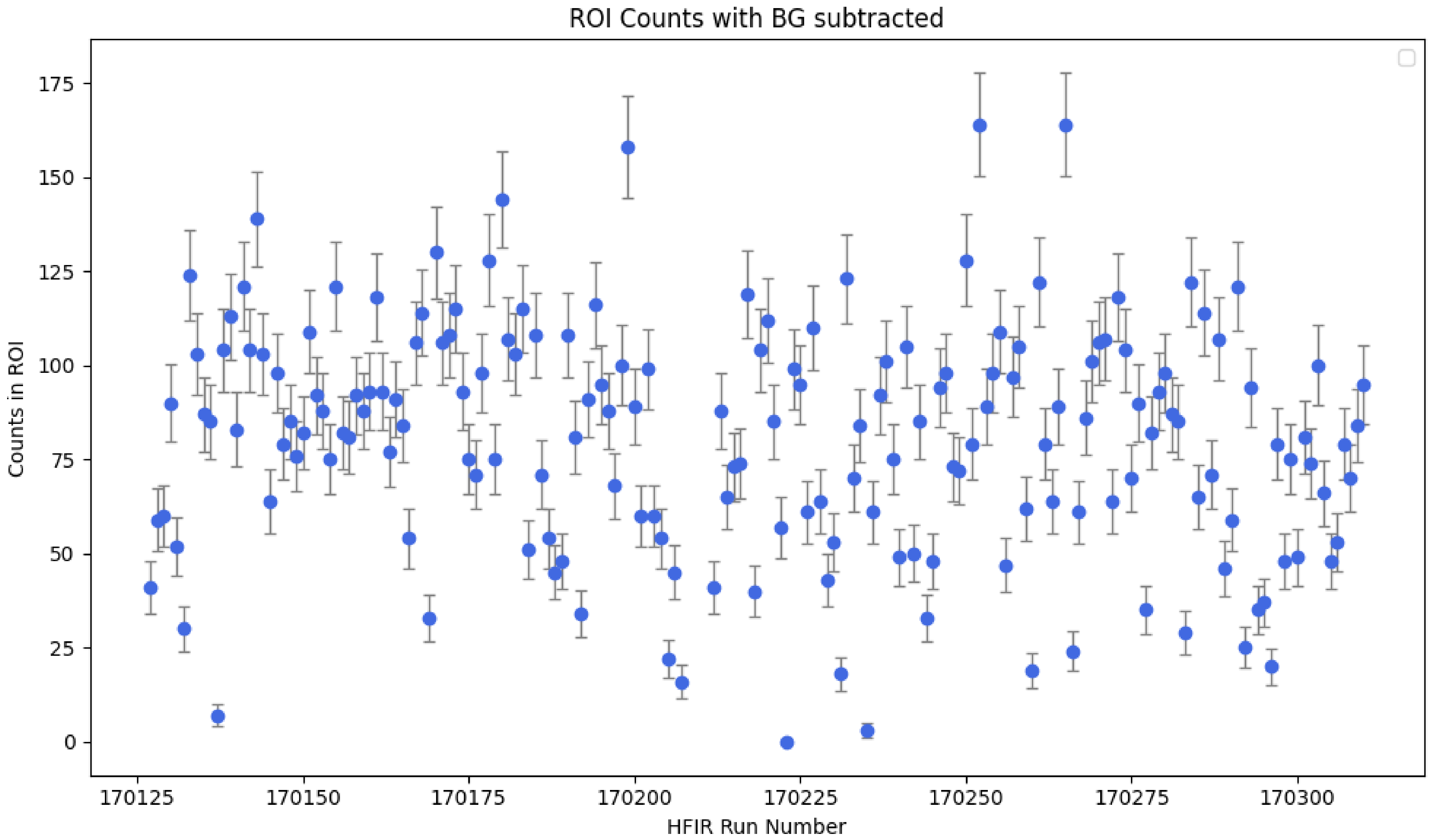
# nTMM2 Counts over time (HFIR run num)



# nTMM2 Counts over time (HFIR run num) contd.



# nTMM2 Counts over time (HFIR run num) contd. 2



# Reference Slides

# Intensity calculation

$$Intensity = \frac{GPMSec * DTCorr * SappAtten}{GPMEff * 2} * 1800$$

nTMM Intensity Correction Factors

| name | value |
|---|---|
| GPM_efficiency | 3.00E-05 |
| deadtime | 1.15 |
| sapphire_window_attn | 0.908 |
| al_transmission | 0.9 |
| si_attn | 0.9315 |
| detector_eff | 0.96 |
| reg_ROI_eff | 0.90156 |
| reg_filteredROI_eff | 0.766972005 |
| si_transmission | 0.91122 |

| | |
|---|---|
| Counts correction | $\frac{RawROIcounts_i * GPMVariationCorr_i}{AlAtten * SiAtten * DetectorEff * ROIEff}$ |
| | |
| Intensity | $\frac{GPMsec * DTCorr * SapphireAtten}{GPMeff * 2}$ |

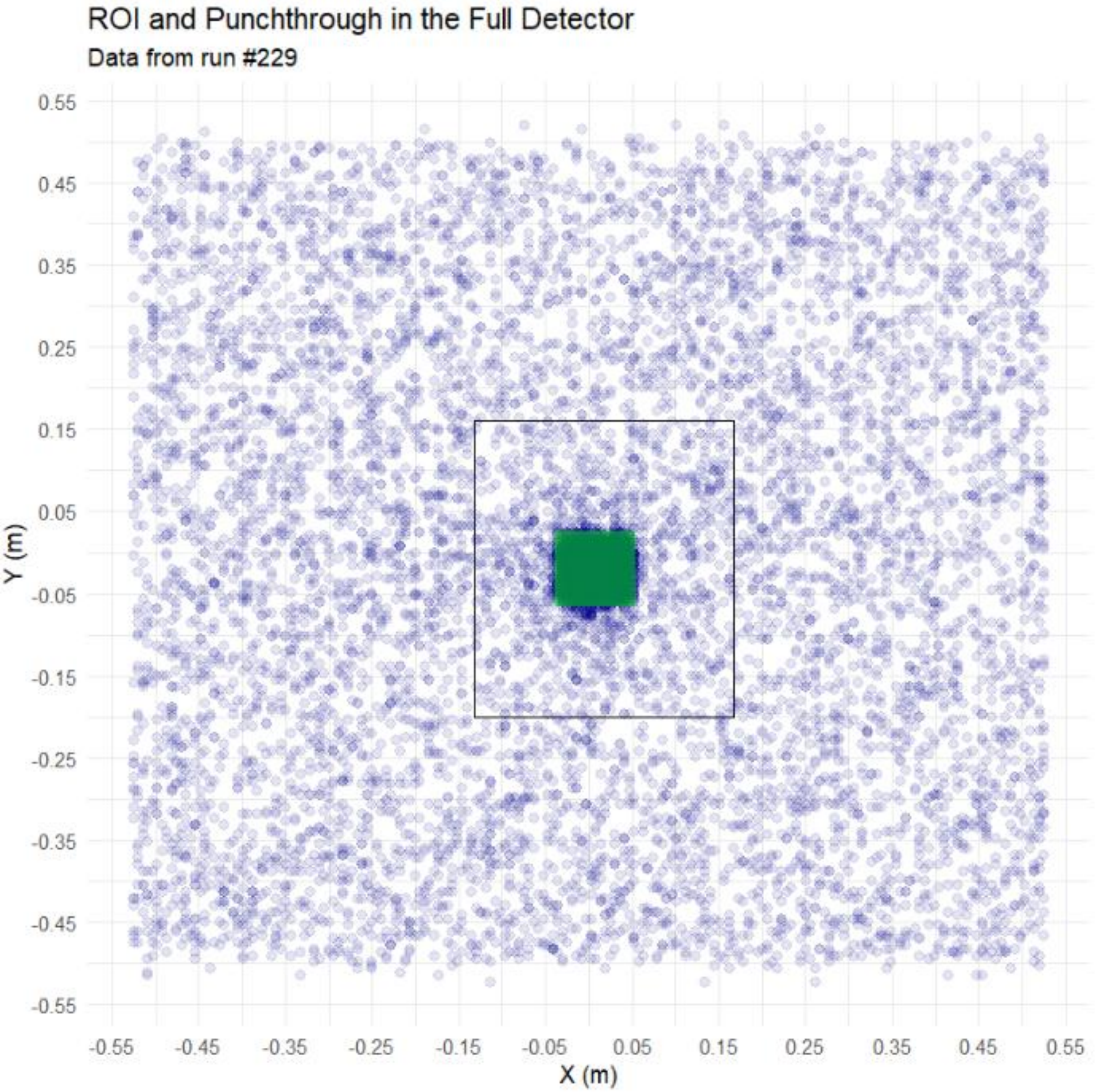
# FC Limit method in python

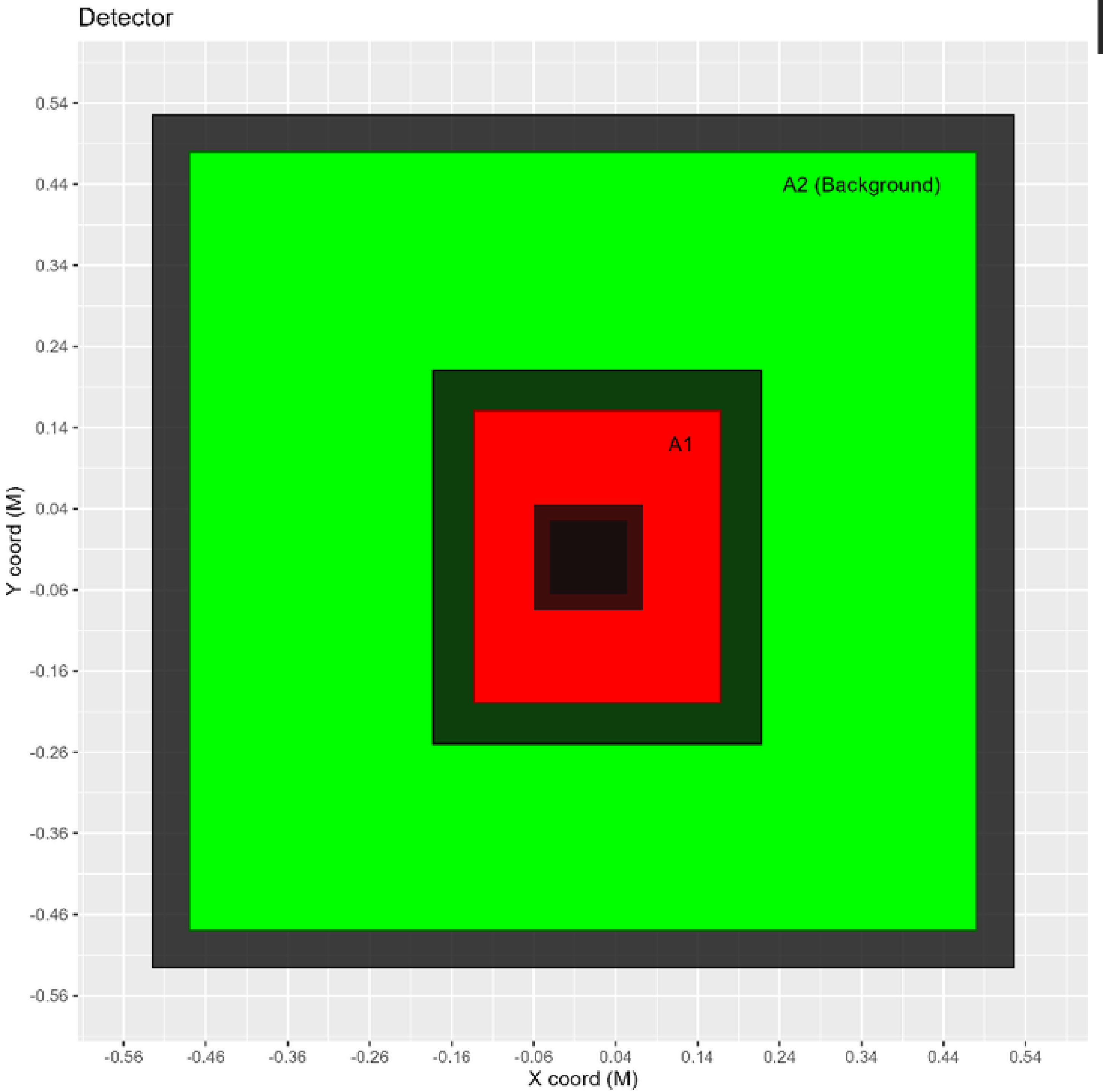
- Clean data
- Define test true $\mu$ range 0 to 8 with 10000 points
  - "If $\mu$ = the tested value, what $x_0$s would be in its acceptance region?"
- Define grid of test $x_0$s -9 to 9 with 10000 points
- For each test true $\mu$ value calculate likelihood ratio R($x_0$) to order the $x_0$s for taking them into the acceptance region
- Add $x_0$s into the acceptance region in decreasing order of R until the cumulative probability =0.95
- Repeat for every tested $\mu$
- Look at the real $x_0$s, find what $\mu's$ acceptance regions they appear in, take min & max of those $\mu's$ to get the limits

- $x_0$ are the observed a parameter estimate values divided by their error
- Approach from part B of Feldman Cousins paper

$$R(x) = \frac{P(x|\mu)}{P(x|\mu_{\rm best})} = \begin{cases} \exp(-(x-\mu)^2/2), & x \geq 0 \\ \exp(x\mu - \mu^2/2), & x < 0. \end{cases}$$

# ROI and Other Area Selections



# ROI and Other Area Coordinates

| Area | X start | X end | Y start | Y end |
|---|---|---|---|---|
| A2 Limits | -0.48 | 0.48 | -0.48 | 0.48 |
| ROI (A1) Limits | -0.13249 | 0.16751 | -0.19941 | 0.16059 |
| ROI + 5cm | -0.18249 | 0.21751 | -0.24941 | 0.21059 |
| Punchthrough | -0.04 | 0.054 | -0.065 | 0.025 |
| Punchthrough + 2cm | -0.06 | 0.074 | -0.085 | 0.045 |

* all measurements in meters

# 2025 nTMM-1 Analysis

Carolyn Haviland | nn' Collaboration Meeting | 09/18/2026

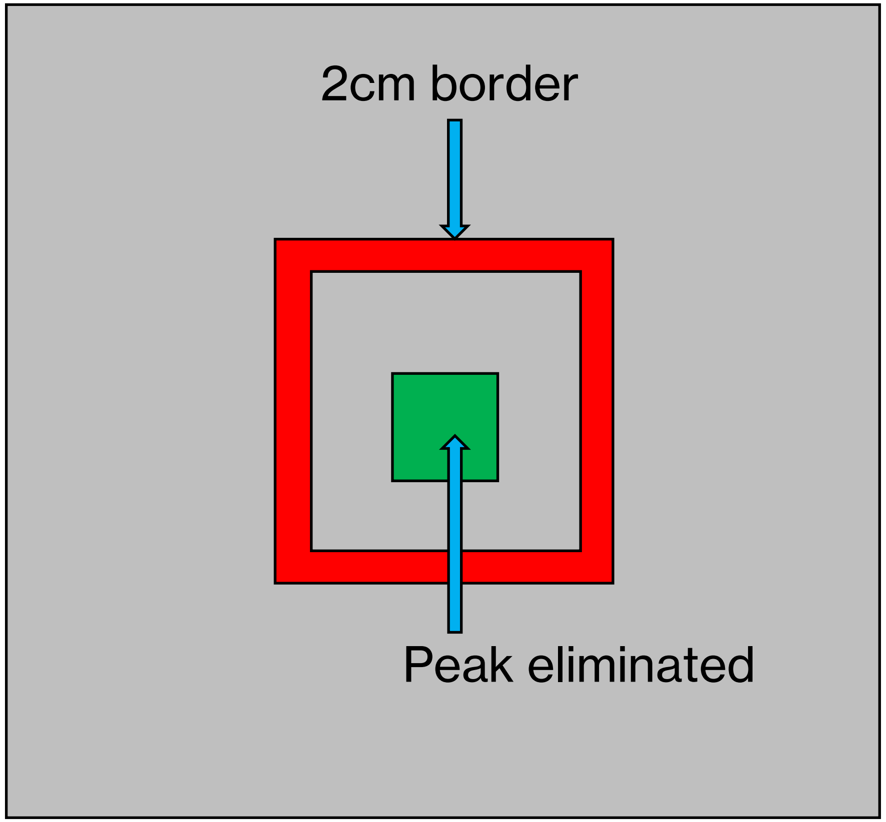
# Agenda

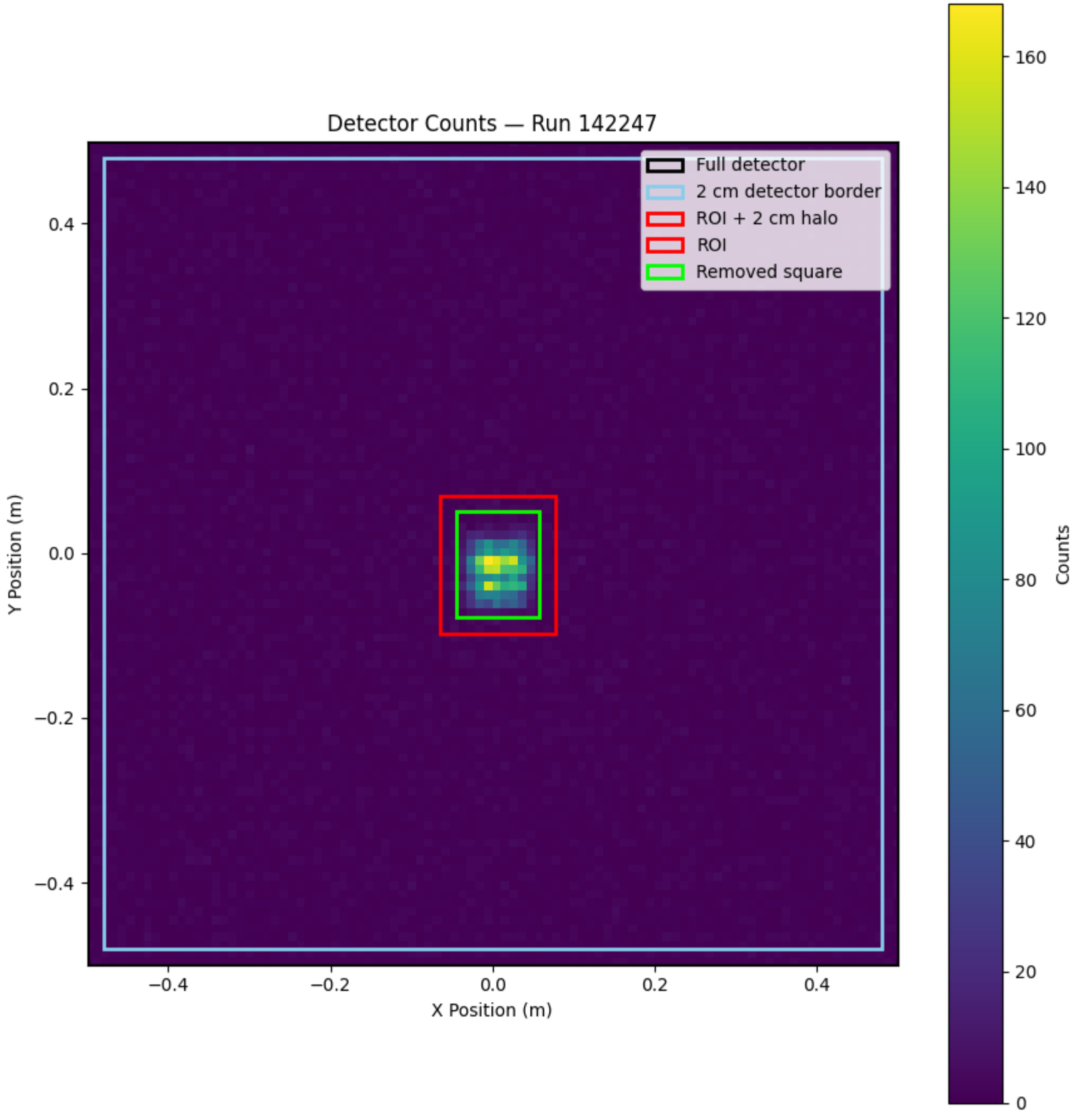
- Analysis procedure
  - Baseline counts
  - Fitting
  - a to kappa
- Findings
- nTMM-2 analysis

# Procedure

1. Plot 2D histogram of each run
   - Make ROI cuts
   - Make peak cuts
2. Output excel with counts for baseline
   - Use area ratios for counts in each section
3. Use counts with fit function
   - Find parameter 'a' at each run
4. Calculate limit assuming no effect
5. Calculate limit with kappa = 1e-5

# ROI and Peak Cuts



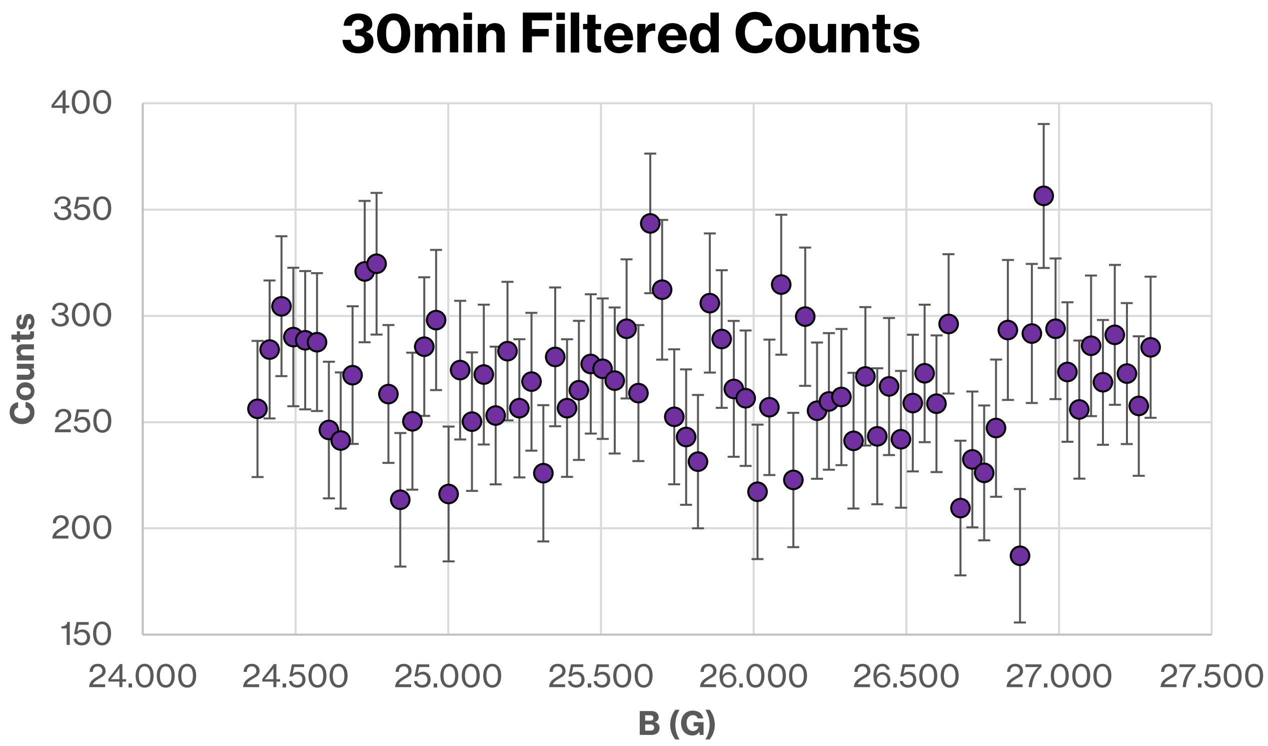



# Correction Factors

- Series of correction factors for intensity and counts
- Counts corrected by GPM reference runs (20min 346, 30min 253)
- Intensity corrected by
    - GPM efficiency: 3e-5
    - Sapphire window: 0.908
    - Aluminum: 0.975
    - Polarization: 0.5
    - Silicon window: 0.911
    - Detector efficiency: 0.96
    - ROI efficiency: 0.7
- Intensity: 5.0336e12

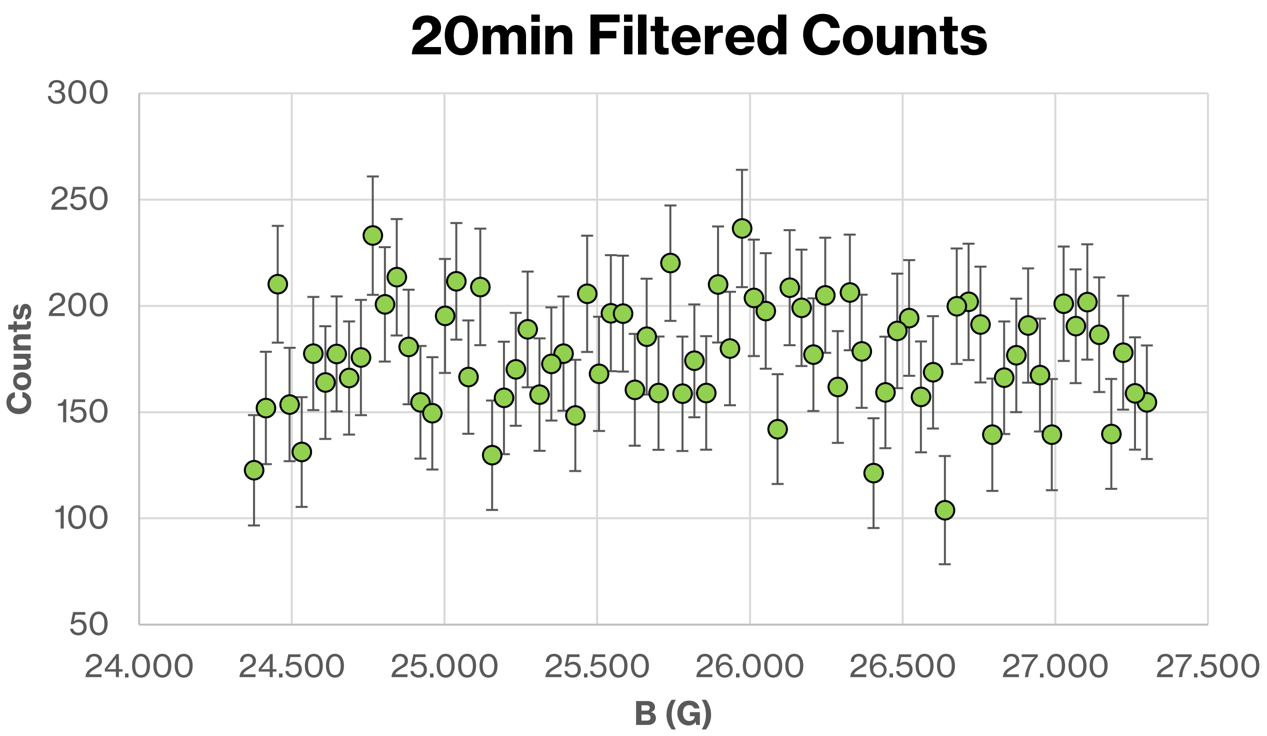
# Baseline

- ROI counts – background = baseline
- Average ~267
  - Used when looking for effect from background
- Each point used for fitting procedure



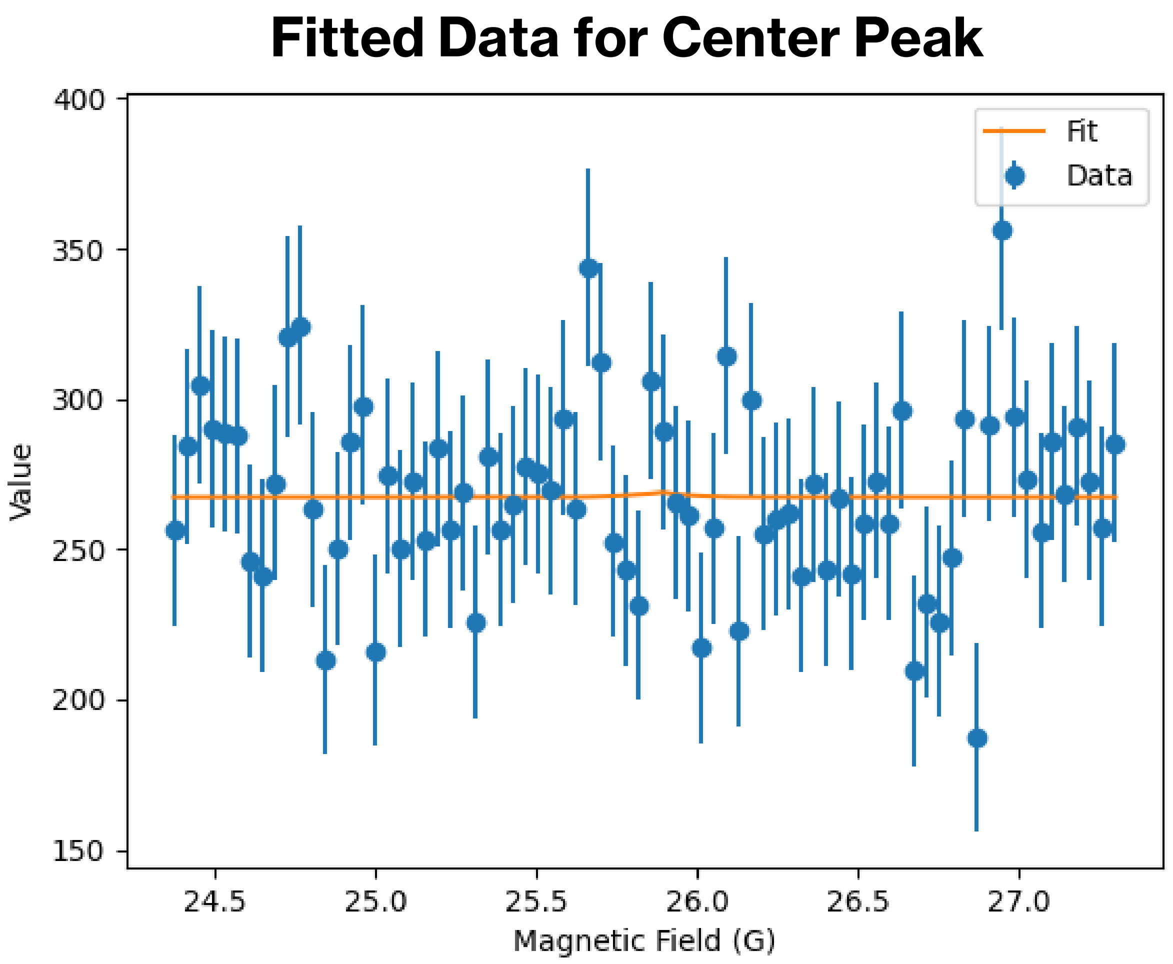
# Baseline

- 20min average ~176

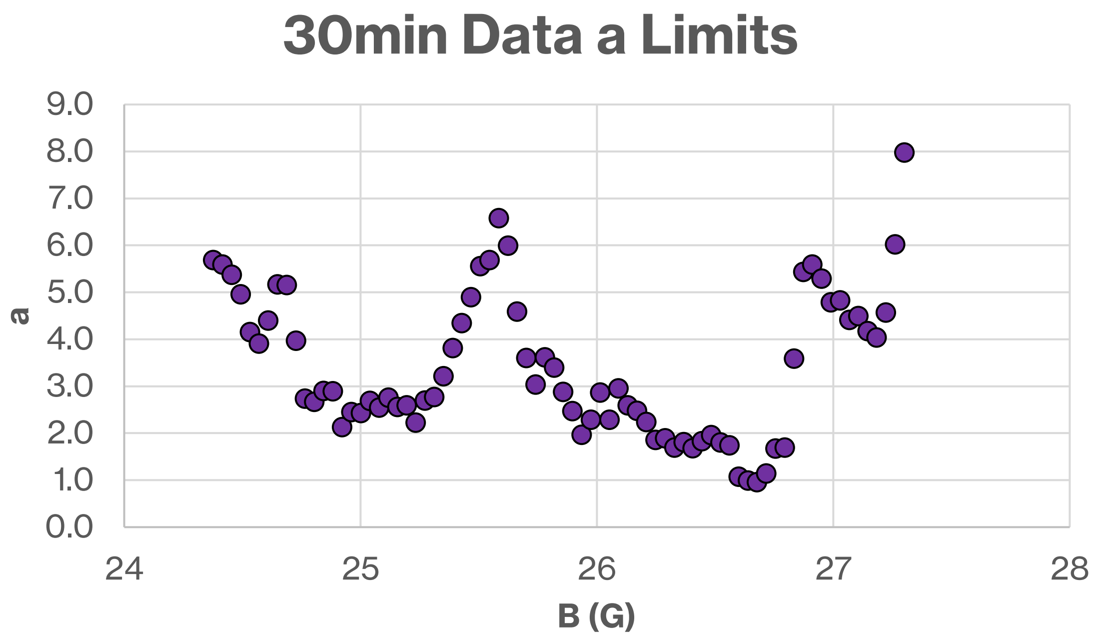


# Fitting

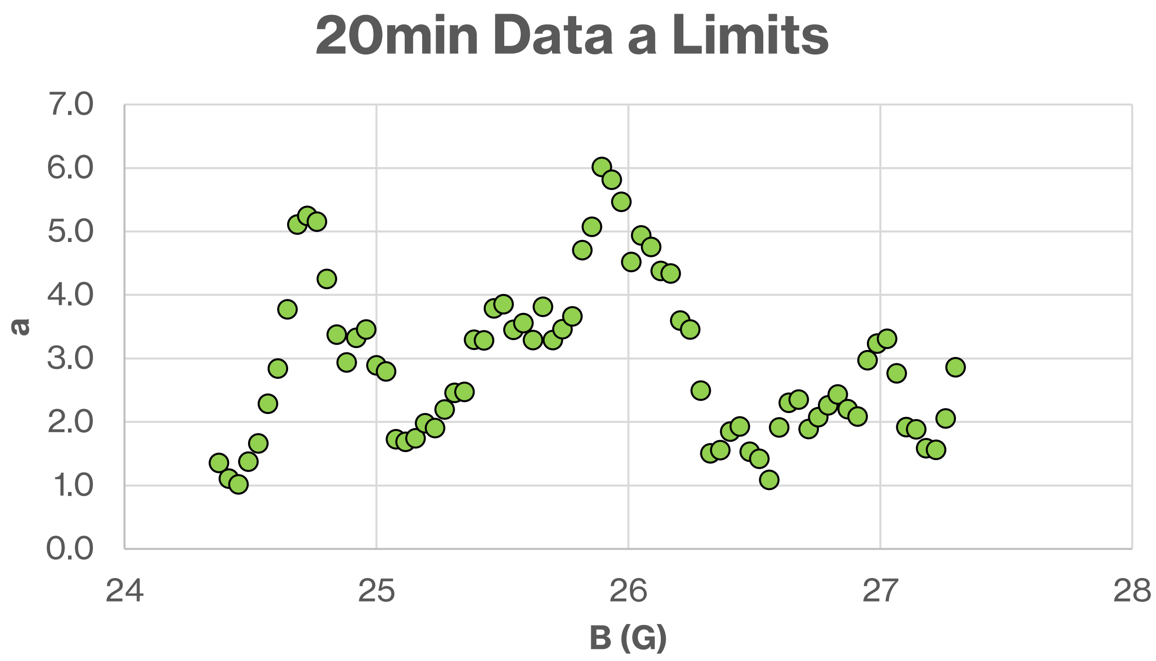
- Data fit to b + a * I * f(a)
  - b = fitted background
  - a = effect in counts above baseline
  - Intensity = 5.0336e12
  - f(a) = template function
- Kappa = 5e-6
- Small peak visible
- Take points and slide fit function across data to extract peak (a value) at each point



# Limits on a



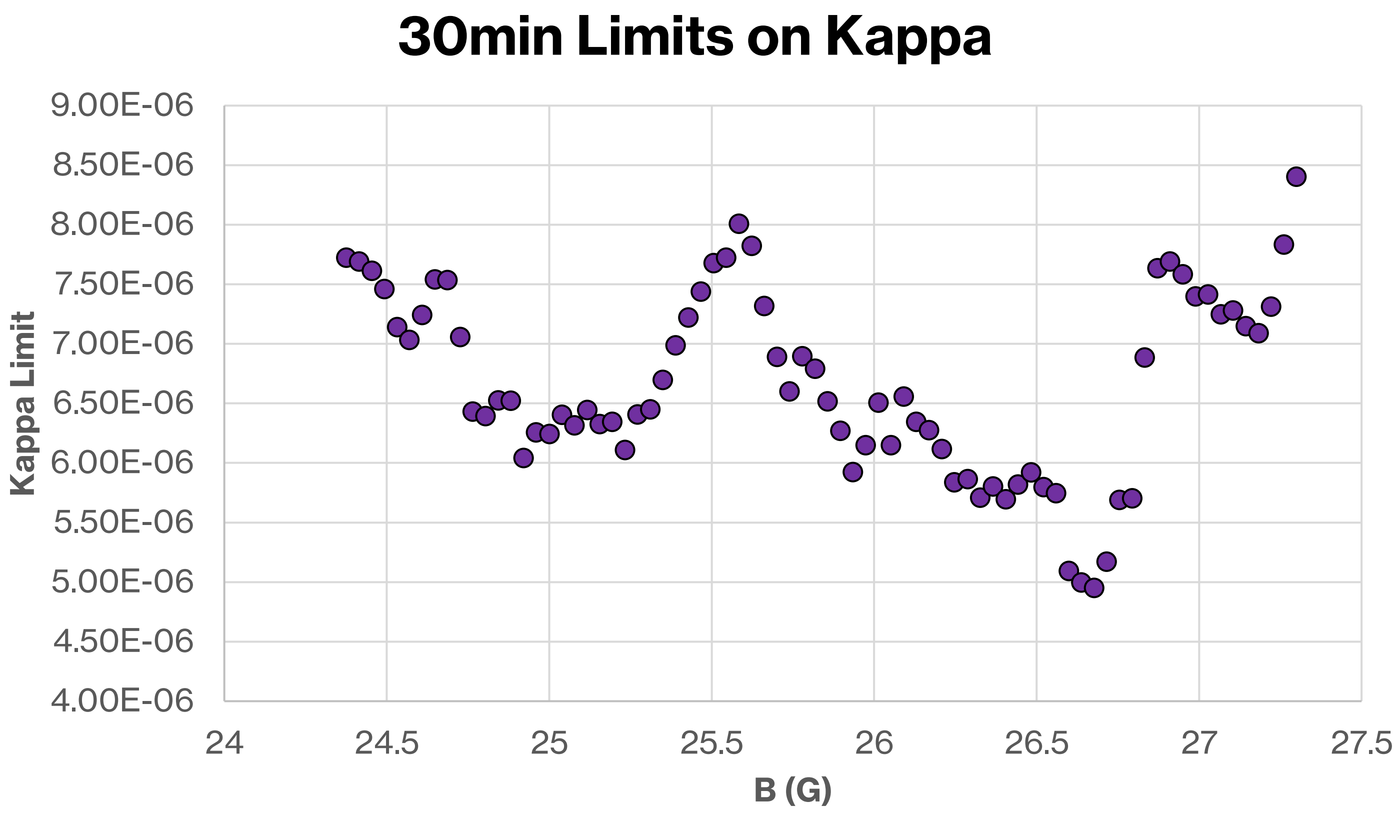
30min Data a Limits
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
a
24
25
26
27
28
B (G)

20min Data a Limits
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
a
24
25
26
27
28
B (G)

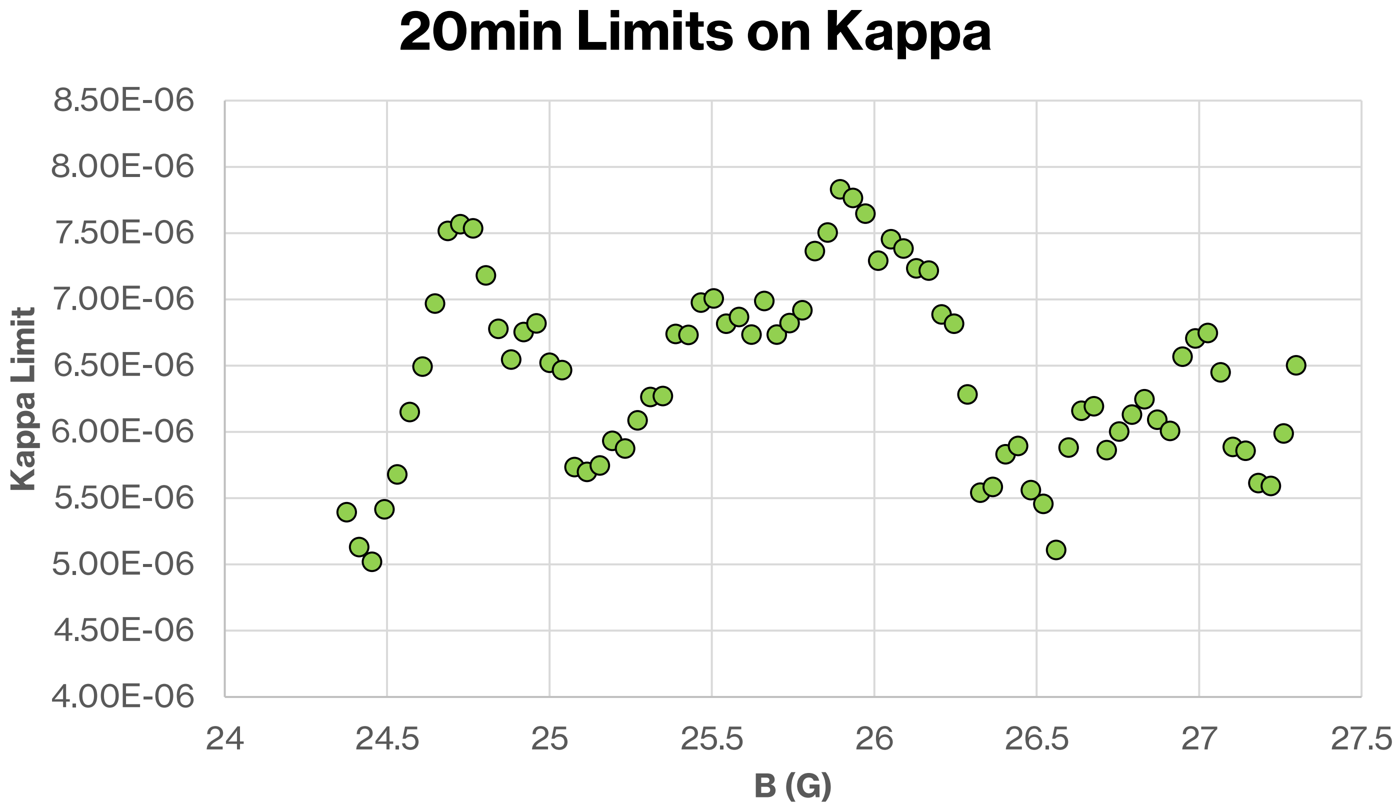
# Kappa from a

- a* = a limit
- Conversion: 5e-6 * $(a*^{1/4})$
- a*: 2.8856
- Center limit: $\boldsymbol{\kappa < 6.27 \times 10^{-6}}$



# Kappa from a

- 20-minute kappa limits
- a*: 6.0163
- Center limit: $\boldsymbol{\kappa < 6.83 \times 10^{-6}}$

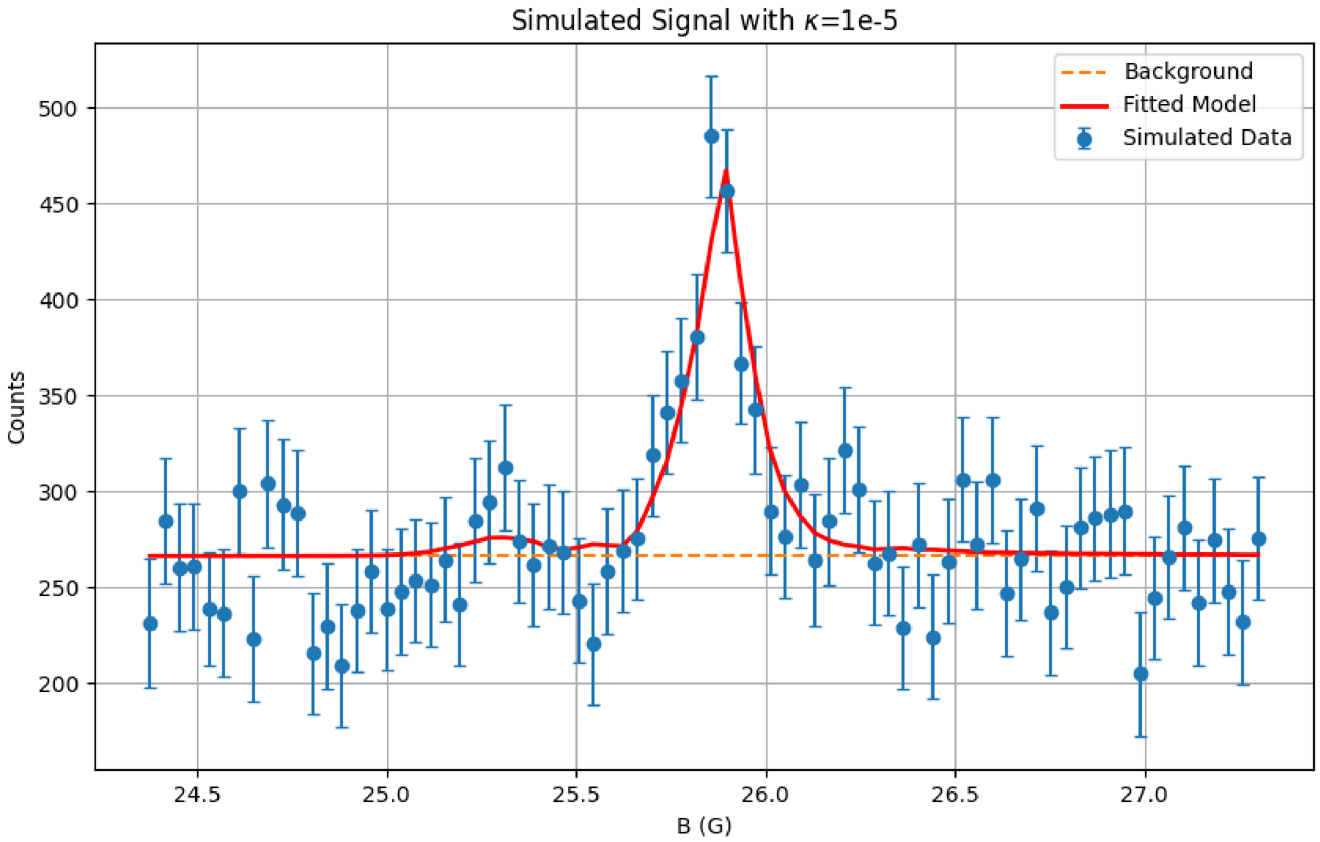


# Simulated Limit

- Monte Carlo simulations
- Only 30min runs
- Extract peak from background
  - Same process as before
- Use base values to generate data sets
- Repeat 1e6 times
- a*:  2.89328
- Kappa limit: $\boldsymbol{\kappa} < \mathbf{6.27} \times \mathbf{10^{-6}}$

# Simulated kappa = 1e-5

- Generated 1e6 experiments
  - Example on right
- Visible peak
- a: 1.0202
- a err: 0.09234
- Calibration:



# Next Steps

- Use scripts and process created from this analysis with nTMM-2 data
- Organize procedure to get Michael and Evan started with analysis

# Magnetics simulation plan for nTMM data
# 2026-09-18

linus.persson@fysik.lu.se

# nTMM-2 data analysis

- Imagine-X magnet was turned off during the full nTMM-2 data collection.
- This means the background environment, dominated by the magnetised support under box 8, remains approximately the same as during nTMM-1.
- We need a strategy for how to simulate the backgrounds and incorporate them into the sensitivity analysis.
- Let's start with a brief reminder from before…

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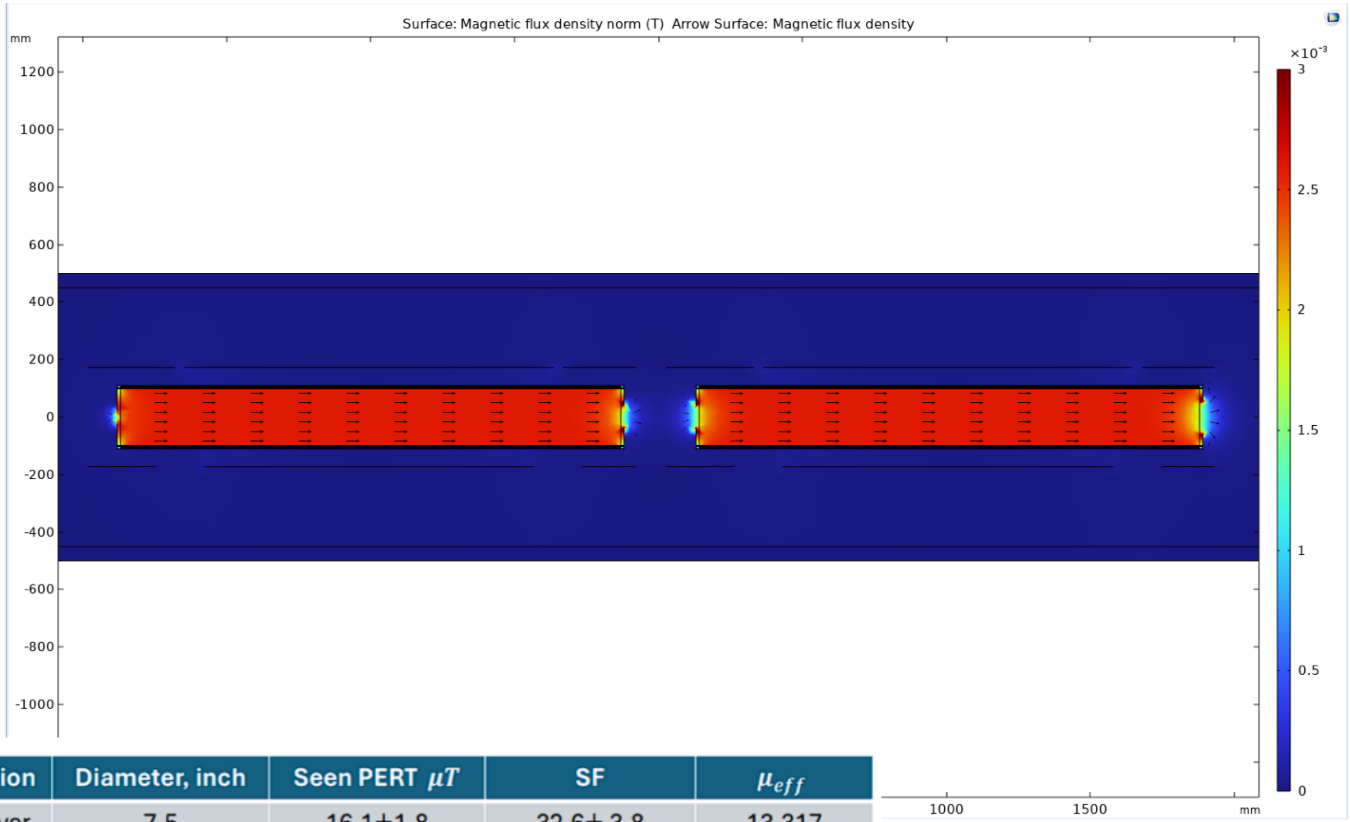
# Simulation of coil field

- Both inner and outer mumetal with 0.6 mm thickness and effective $\mu$ from UT prototype measurements.
- Individually modelled coil layers.
- This model gave a current-to-field conversion factor of 97.91 G/A.



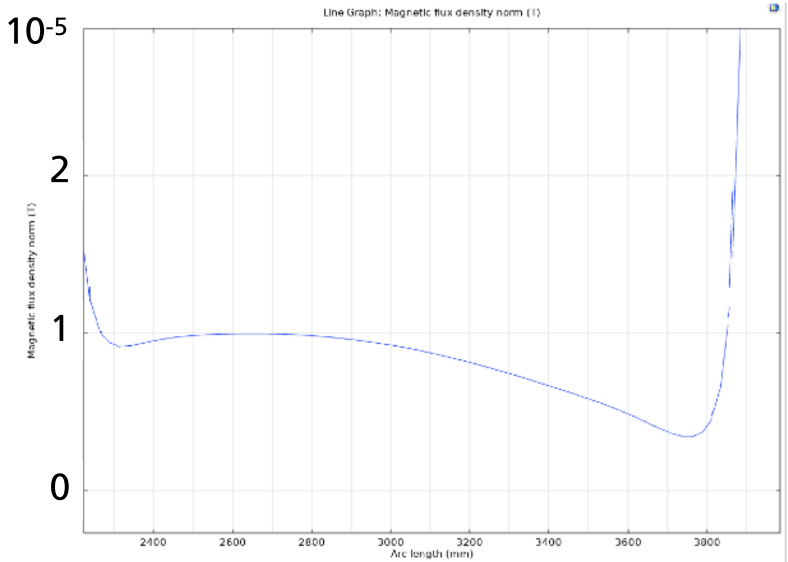

Result from Mubi (18/8), can be updated

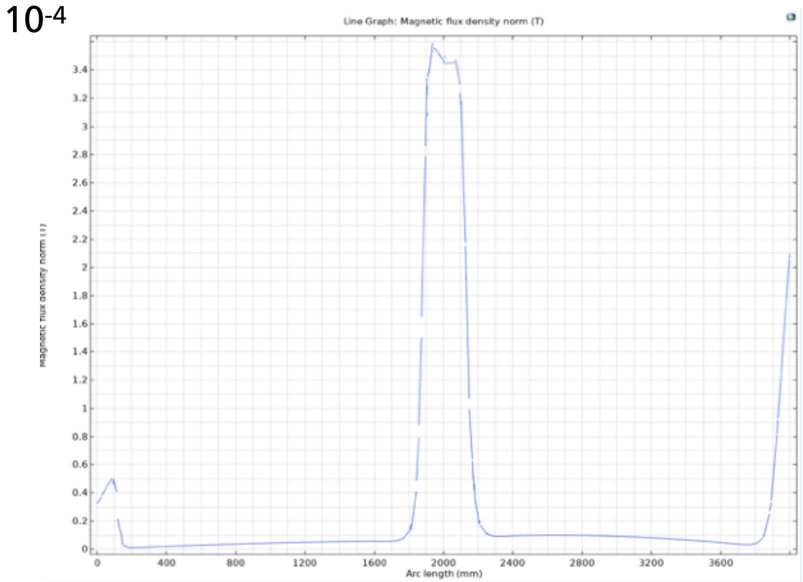
| | Configuration | Diameter, inch | Seen PERT $\mu T$ | SF | $\mu_{eff}$ |
|---|---|---|---|---|---|
| only | $1\mu$ inner layer | 7.5 | 16.1±1.8 | 32.6± 3.8 | 13,317 |
| only | $2\mu$ inner layer | 7.6 | 4.51 ± 0.61 | 116.2±16.1 | 24,050 |
| only | $1\mu$ outer layer | 9.0 | 27.6 ± 3.7 | 19.0±2.6 | 11,220 |
| only | $2\mu$ outer layer | 9.1 | 7.9 ± 1.1 | 66.3±9.4 | 19,794 |

$\underbrace{\text{Seen PERT, SF, } \mu_{eff}}_{\text{Prototype measurement}}$

# Magnetic scalar potential simulation

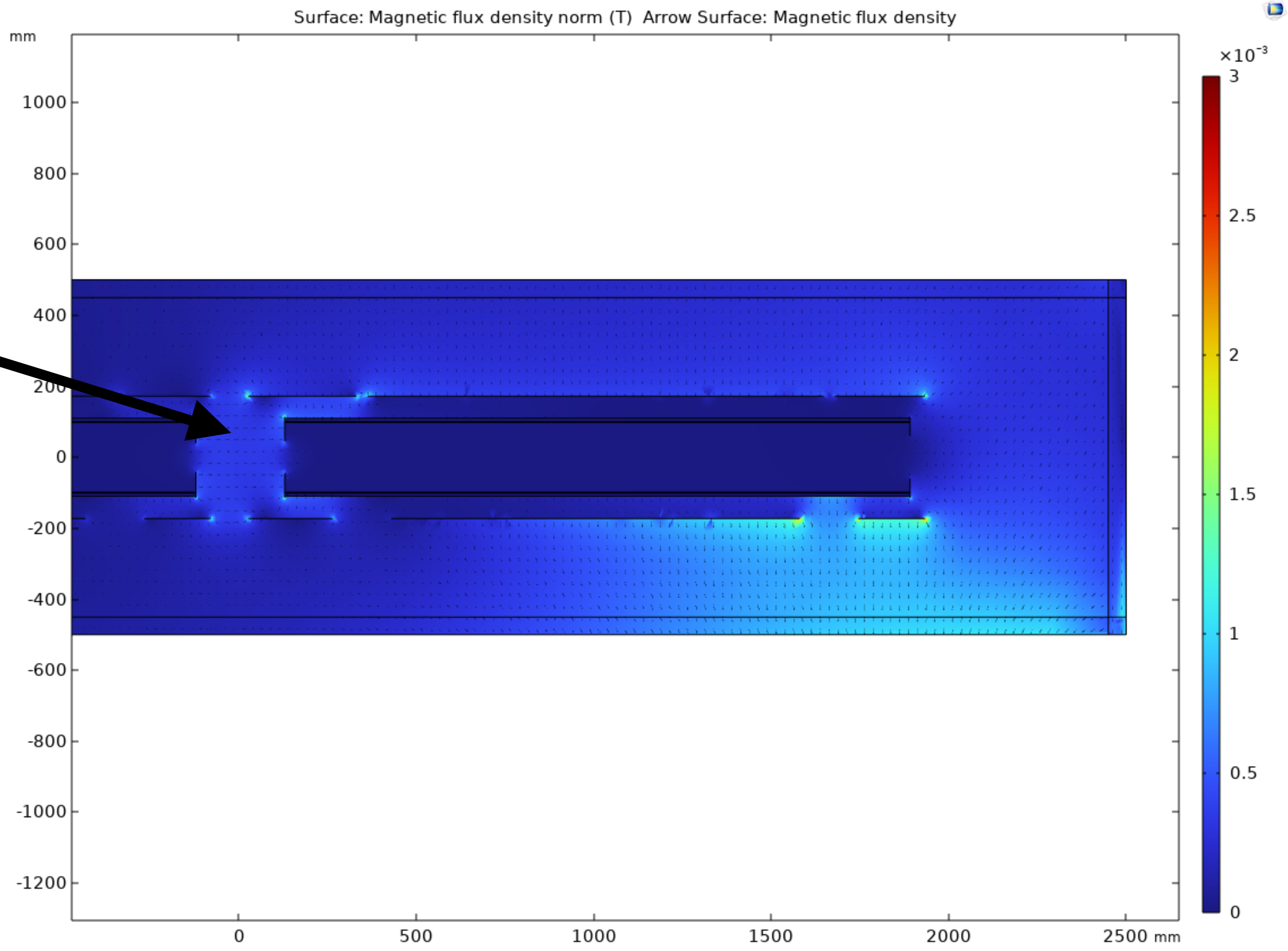
- I used a low-order approximation ($L \leq 6$) spherical harmonic fit from German and applied on the new model for the background.
- Infinite element domain with scalar potential boundary condition.
- This is very similar to German's results.
- Field between the magnets is much larger than expected (~350 μT), but is supported by simulations in constant longitudinal background field.
- Additional scrutiny needed.



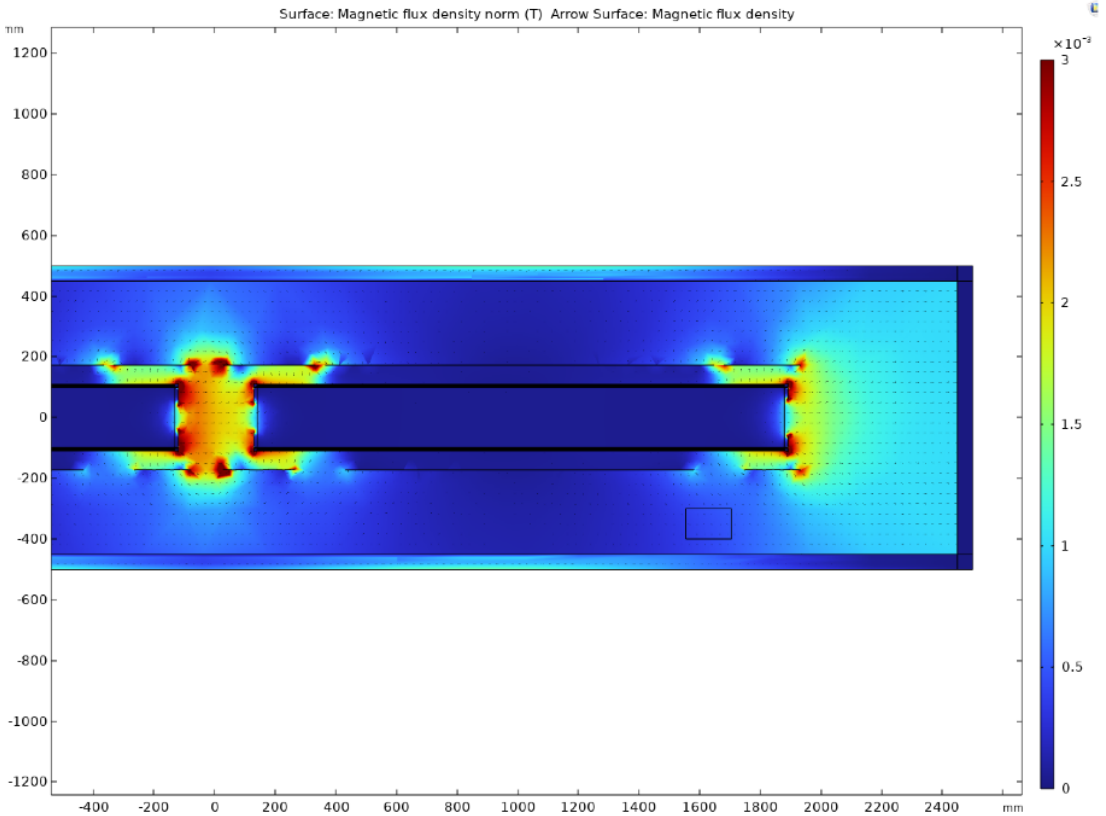
# Simulation with magnetic scalar potential

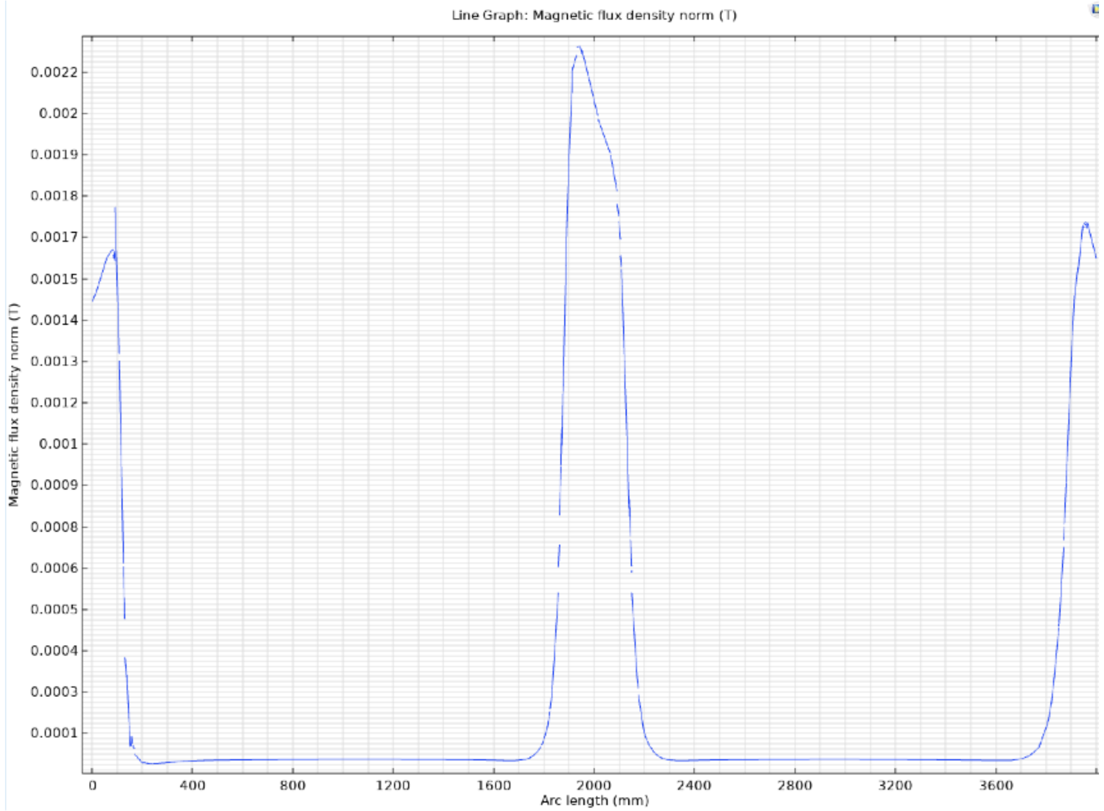
The field between the inner shields is stronger than the field outside



# Simulation with horizontal background field

- Notice a large amplification in field strength where field lines jumps from the outer mumetal layer in one magnet to the other.

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# Suggested analysis strategy

- Simulate full beam profile every 1 mm along the axis by adding (as vectors) the perturbation field and the field generated by coil current.
- Verify transverse homogeneity of the field.
- Verify that higher-order expansion of spherical harmonic results converge for large $L$.
- Use the new B-field curve to calculate the regeneration probability curve as a function of applied magnetic field.
- Use the input function shape as input to Alina/Carolyn's analysis workflow to extract nTMM sensitivity.

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# Disclaimer: Highly preliminary results coming up

(i.e done in an airport or the back row of a conference)

# Input to updated sensitivity analysis

- I used the coil simulation that determined the current scan interval for the generated field.
- I used the low-order scalar potential fit ($L \leq 6$) discussed previously for the background field.
- These were added as vectors and the total magnitude was used as input to the Python version that I made of Yuri's Fortran script (based on Berezhiani's formula).
- Simulations were performed for relative nTMM $\kappa = 5 \times 10^{-6}$.
- Note: For now I only included the cadmium absorber, not the borated polyethylene (although this should not have a major effect), what is the exact thickness and placement of all materials relative to the beam direction?

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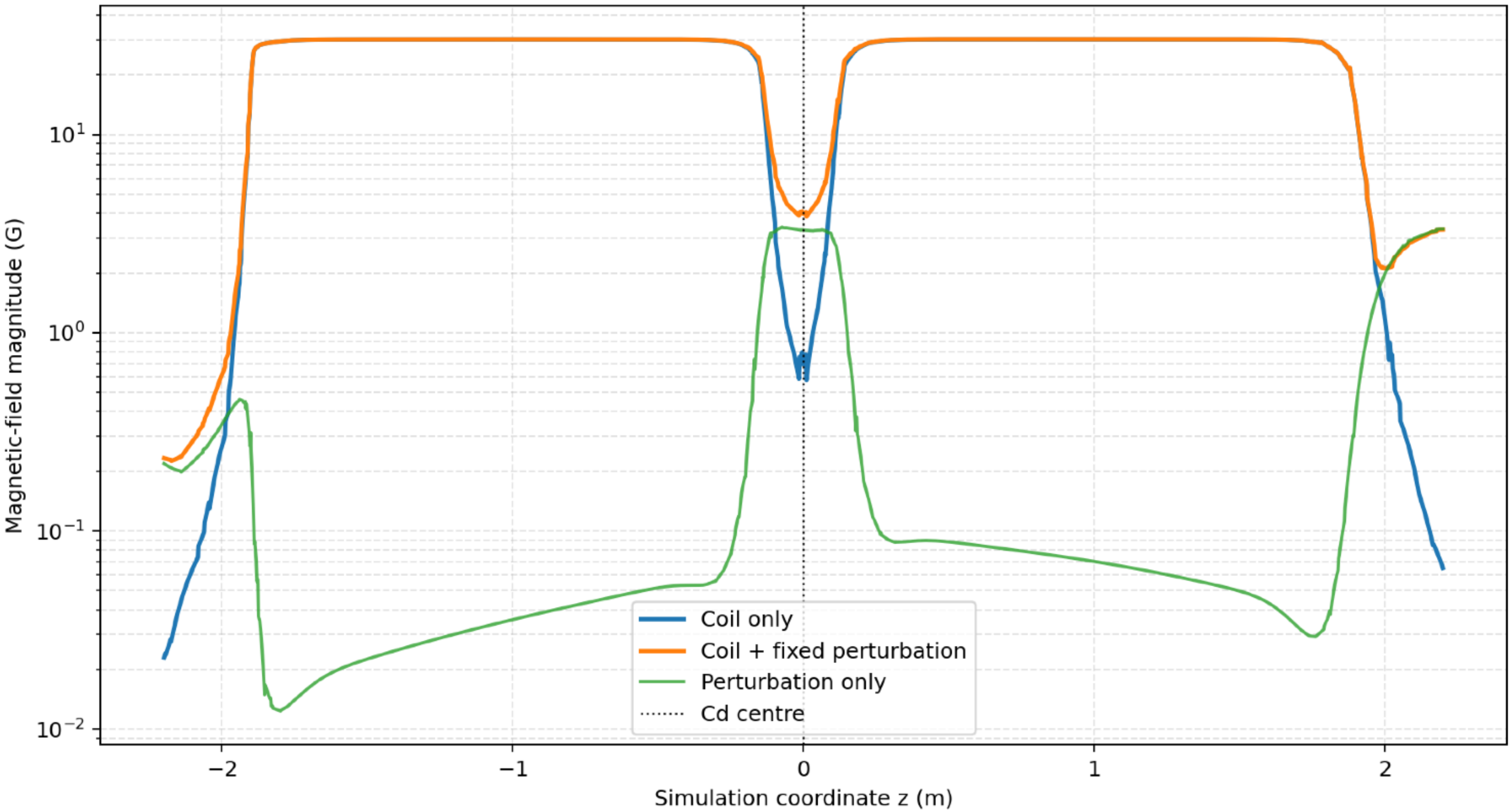
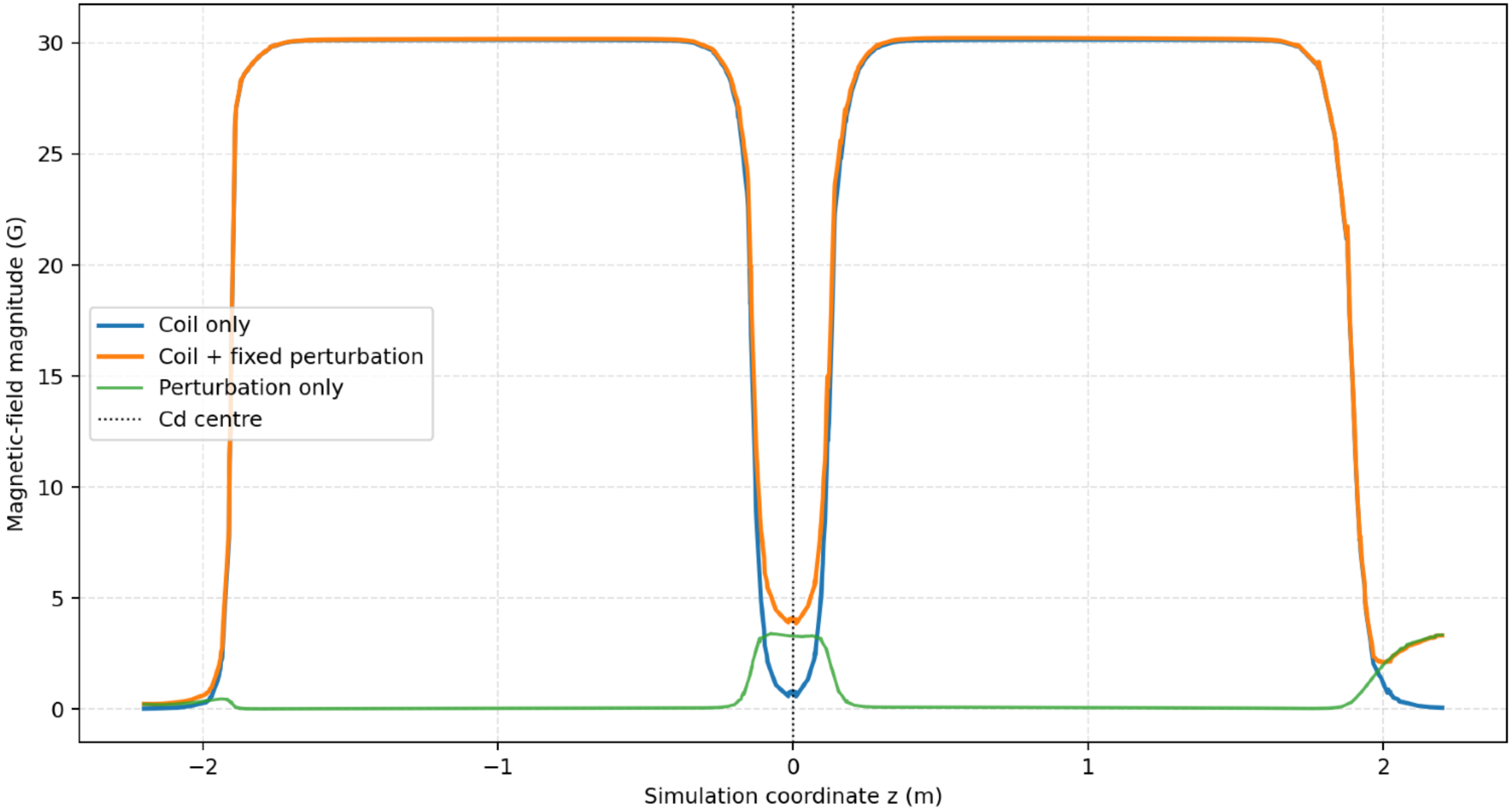
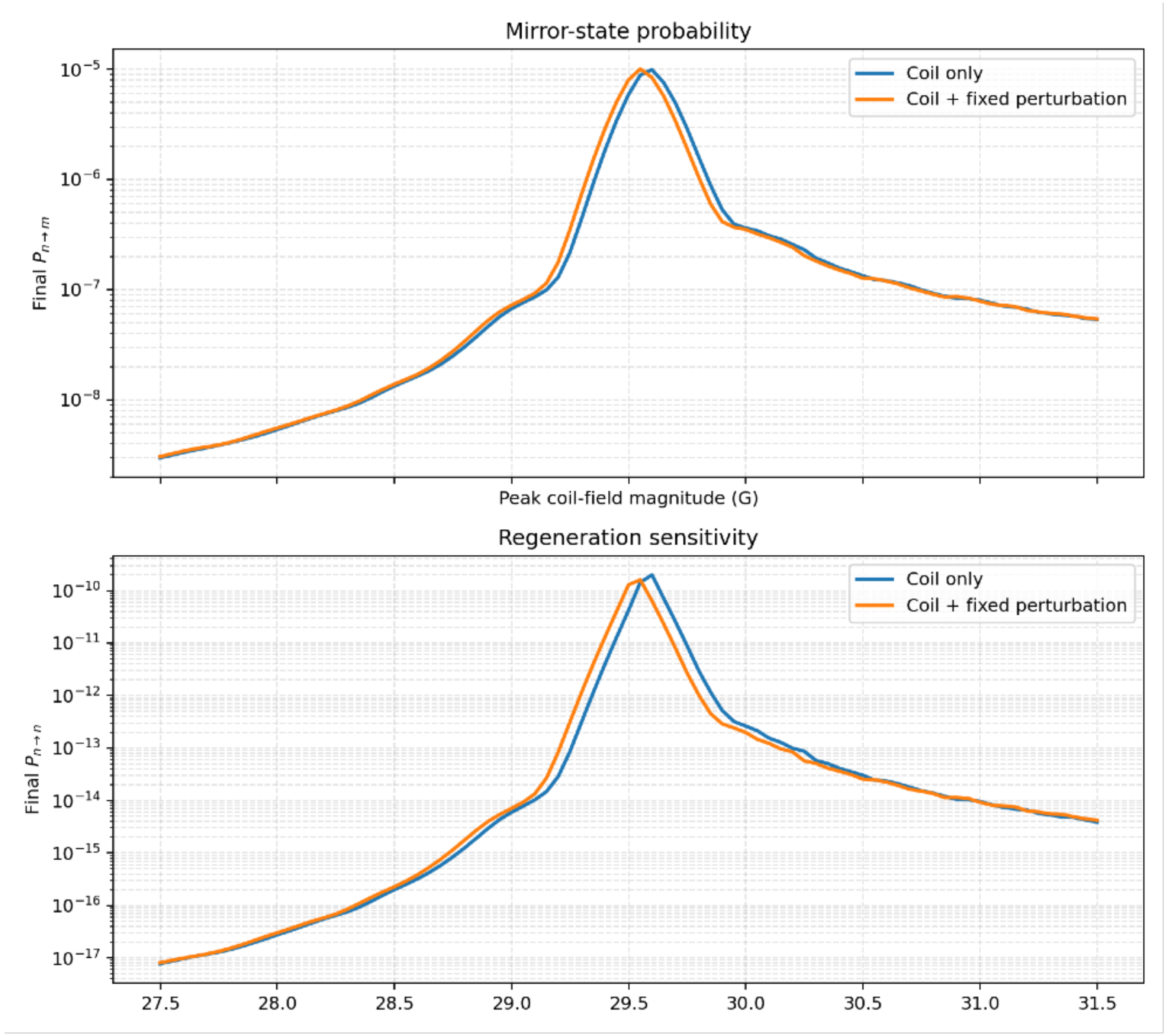
# Field profile (log scale)



# Field profile (linear scale)



# Resonance shape (log scale)

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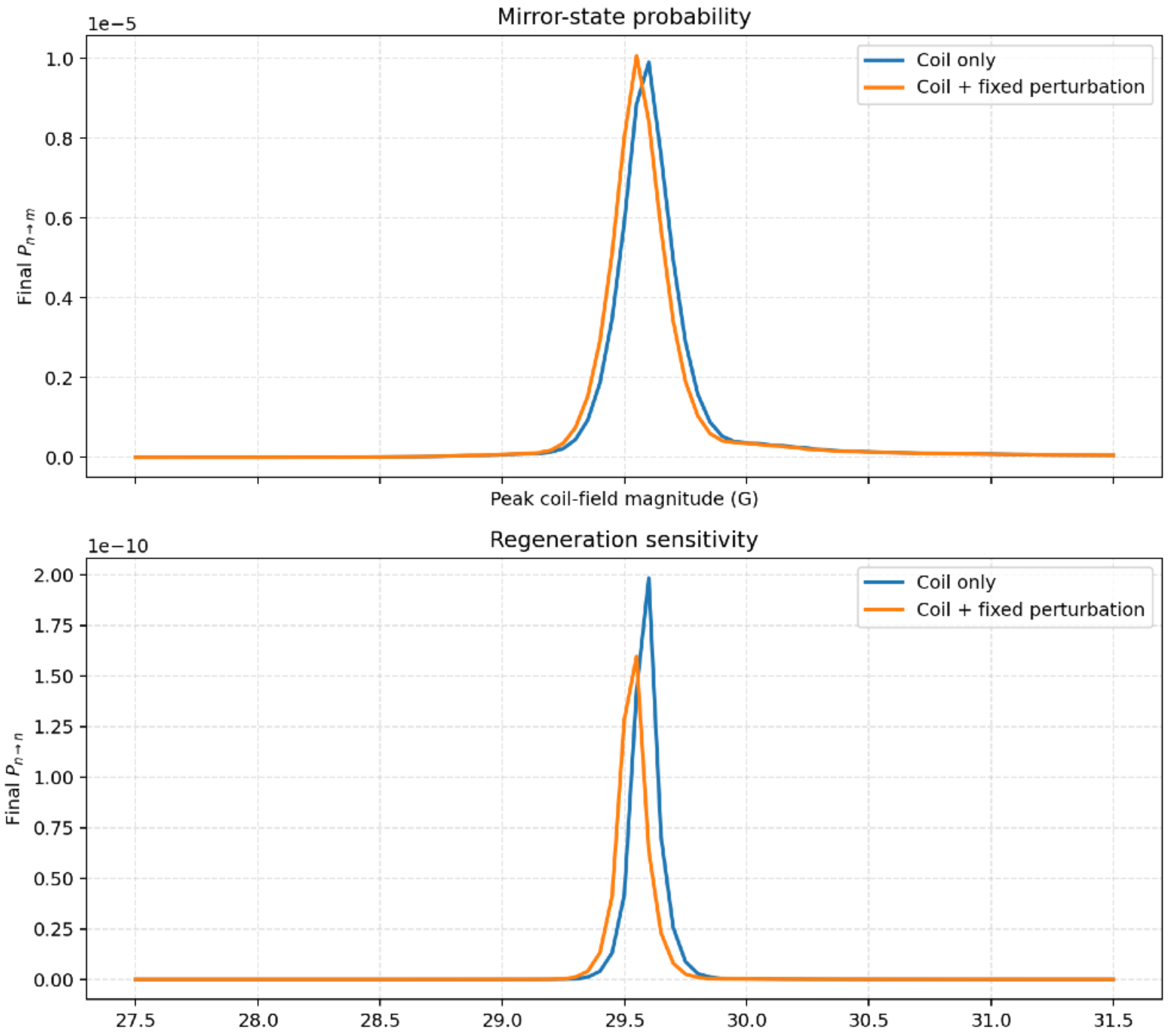
# Resonance shape (linear scale)



# Conclusions

- The peak appears at roughly 29.5 G, consistent with expectations and the chosen current scan range. The ”coil only” case gives approximately the same peak regeneration probability as the calculations from Yuri.
- When including the background fields, the peak probability drops by about 20% and shifts to lower coil fields (0.05 G). This makes sense since the background field makes the total field slightly larger.
- A small broadening in FWHM of about 8% is also seen. This can be understood intuitively as the region with correct field is smaller at a given current but reachable from more current settings.
- This is encouraging, but several tests remain before being publication-ready, including full understanding of the effective $\mu$, understanding of scalar potential convergence and transverse field homogeneity.

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# Optical Character Recognition for nTMM-2

Evan Michael - University of Tennessee

- nn’ Collaboration Meeting -

9/18/~~2026~~

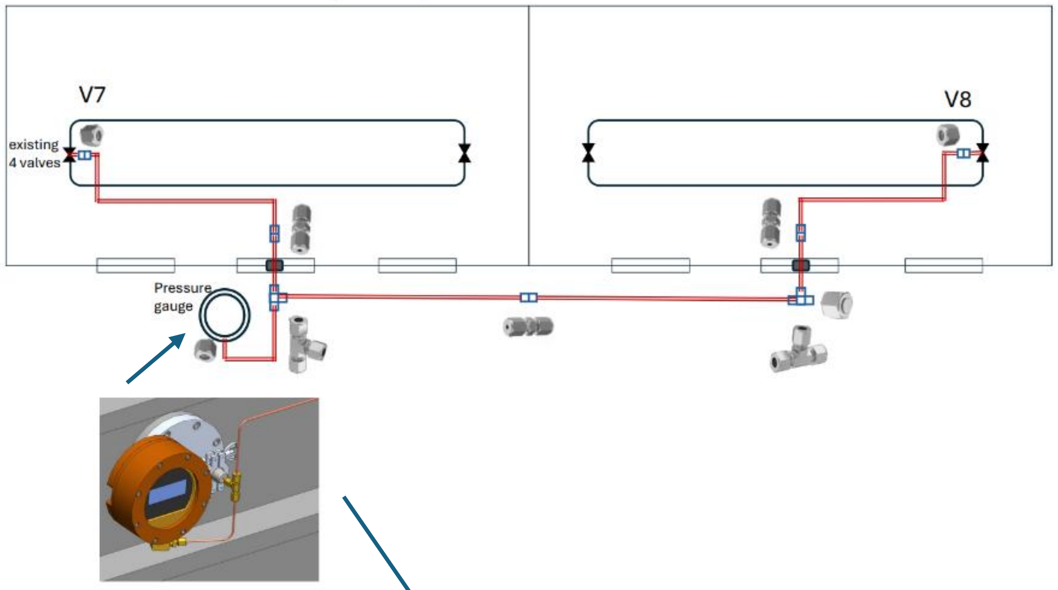
# Overview

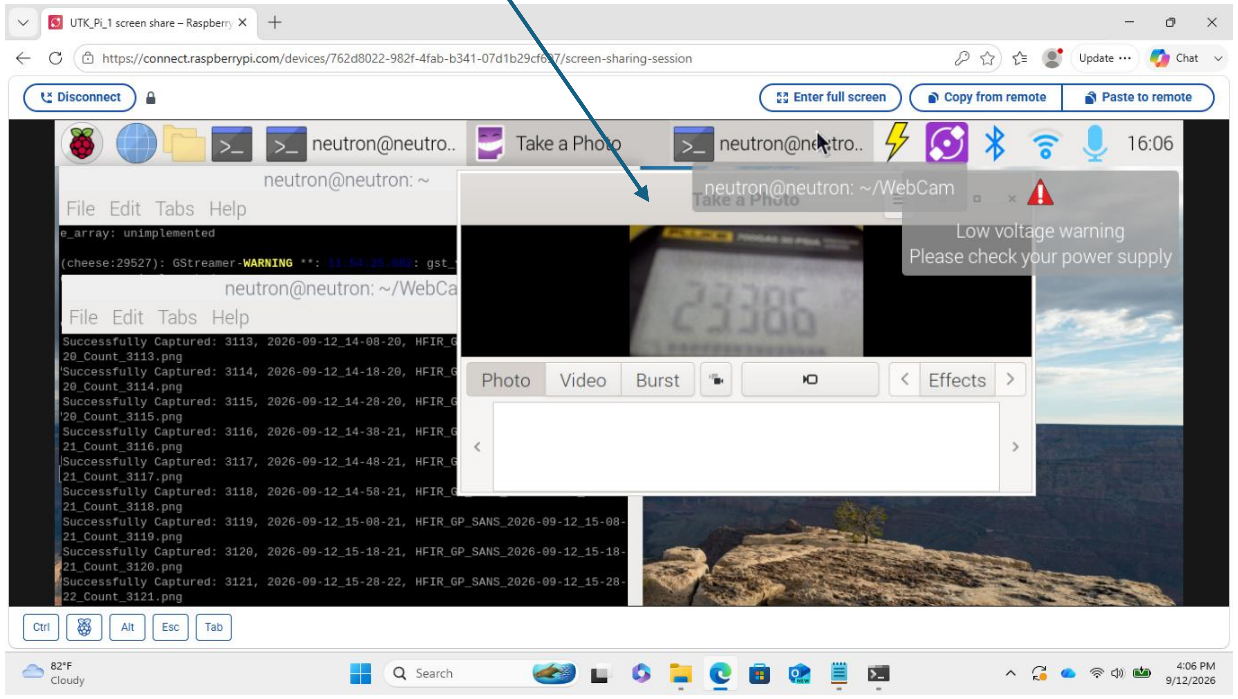
- Changes in electrical current throughout the experiment heated and cooled the magnets through resistive heating, causing $CO_2$ gas pressure changes throughout the runs.
- The time of day also lead to notable fluctuations in the temperature of the magnet.
- $CO_2$ gas pressure readings and temperature readings must be reconciled to understand their correlation throughout the runs.
- This correlation will allow for a correction to the density of the $CO_2$ gas and thus a further correction to the calculated Fermi optical potential.

# Pressure Guage Readout

- Analysis of nTMM-1 (2025) found that there was a 2% difference in $CO_2$ gas pressure.
- A gas line was added to the magnets for nTMM-2 (2026) to maintain equal pressure in both vessels.
- The connected system was monitored by a single gas pressure gauge, whose reading was recorded via camera in the 2026 runs.
- The pressure readout from the gauge was captured every 10 minutes.

Schematic of nTMM-2 Gas Line

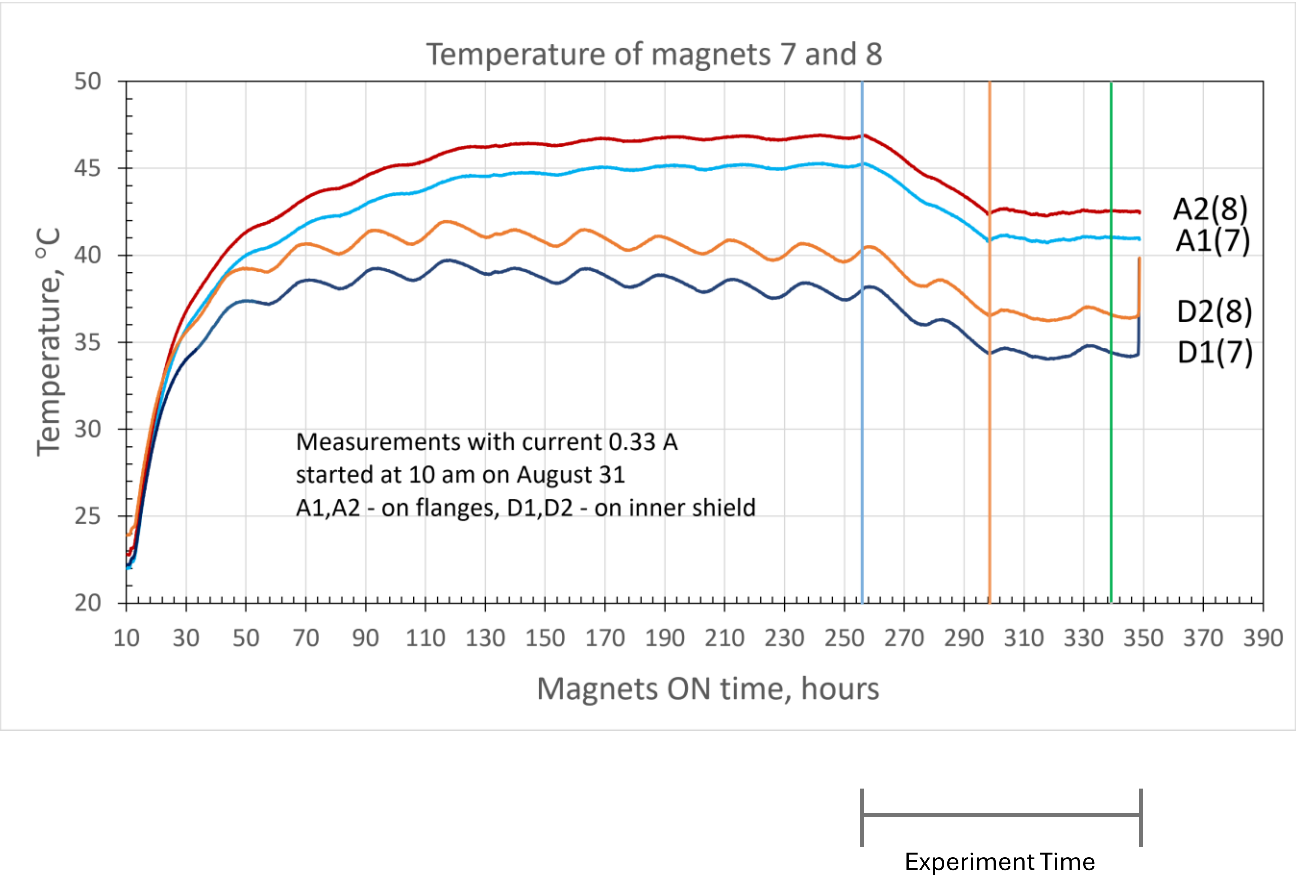



Raw Pressure Capture (Uncropped Image)

# Thermocouple Readout

- Four thermocouples are attached to each nTMM-2 magnet to monitor temperature changes throughout the runs.
- Two thermocouples on the outer flanges, two on the inner Mu Metal shielding layers.
- Temperature changes are due to resistive heating and cooling as the electrical current changes through the runs.
- Temperature fluctuations from daily environment are also present.
- The readouts of the thermocouples are recorded digitally every 5 seconds.



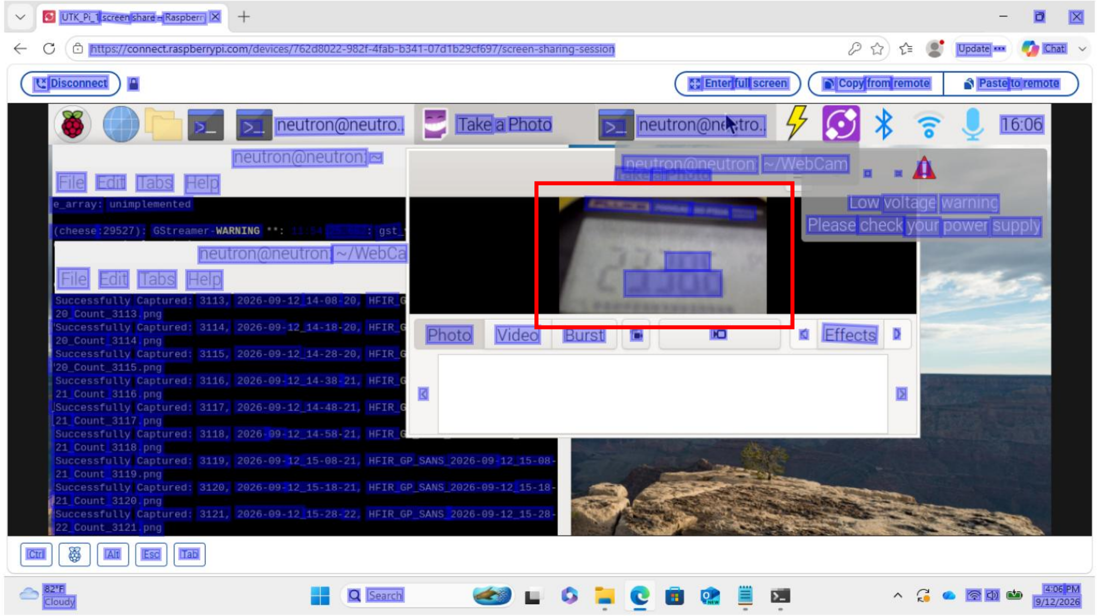
# Temperature-Pressure Relation

- A temperature-pressure relationship of the $CO_2$ gas throughout the runs should be established calculate gas density throughout the runs via a NIST calculator.
- Knowing the density allows for corrections to calculations of the  Fermi optical potential in the experiment.
- This can be accomplished by pairing coinciding pressure and temperature data throughout the runs.
- Challenge: 500+ pressure captures are difficult to manually catalog.
- Solution: Use an Optical Character Recognition (OCR) machine learning model to detect (locate the text), recognize (read the text), and catalog pressure readings.

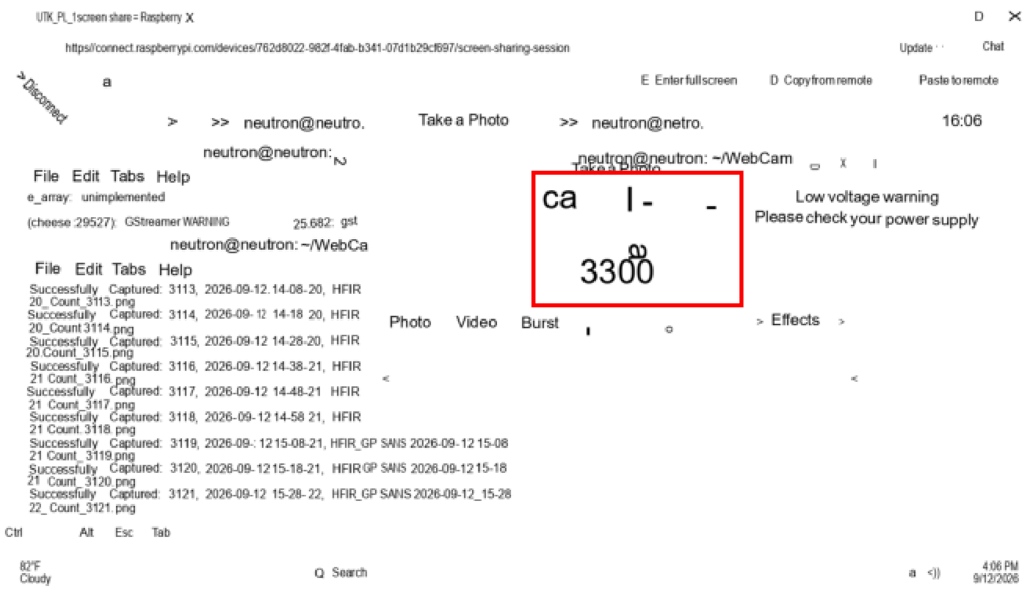
# OCR Implementation

- Method 1: Utilize a pre-trained OCR deep learning model and immediately deploy on pressure captures.
  - First attempted with the PyTorch-based docTR model. Unsuccessful in both detection and recognition.
  - The model is not trained on the seven-segment number font on the gauge display.
- Method 2: Use a standard deep learning OCR model and train it on datasets of seven-segment digital display images, then deploy
  - Example: train a YOLOv8 model (also PyTorch-based) on a large dataset, then deploy to extract pressure data from captures.
  - Train the model on images of various lighting, orientation, and resolution to account for grain and tilt of display on pressure capture.
  - Require manual input if confidence score falls below set percentage.
  - Work in progress

docTR Detection Results (blue box = text)




docTR Recognition Results (what the model sees)



# Seven-Segment Training Dataset

Example: YUVA EB dataset (image credit: MathWorks)


- After recording pressure, pair with average temperature of coinciding time (via a Numpy array) for use in calculations

# Plans and projects for 2026 data analysis

Yuri Kamyshkov / UTK

1. Recover $CO_2$ pressure from camera shots (every 10’) (Evan)
2. Recover and sync temperature recording from Data Logger
3. Correlate Pressure and average Vessel Temperature. Functional dependence.
4. Use this function for Optical Potential calculation for each run
5. Estimate error or Optical Potential reconstruction
6. Understand spatial distribution of background in the detector. Use it for subtraction in ROI
7. Understand reason for different $\mu$ from single & double layer in mu-prototype (Mubi + Linus)
8. Using $\mu$ for inner and outer double shield suppression factor measurements

   calculate 3D profile of magnetic field in magnets with external perturbations (Mubi + Linus)
9. Estimate error in magnetic field reconstruction
10. Using corrected O.P. and $B_{total}$ (z), calculate nTMM expectation function (used by fit) 2000 velocities averaged
11. Estimate effect of neglecting B(x) and B(y) in nTMM expectation function calculations, Spin rotation?
12. Check time uniformity of GP monitor
13. Find GPM dead time correction
14. Check that there is no anomalies in magnet currents

14. Update on Scattering and absorption in beam windows for nTMM configuration (Mubi)

15, Estimate errors in intensity

# Publication scenarios for nTMM data:

Yuri Kamyshkov / UTK

0. Can we combine all 180 points (all 30 min) into single data set for theory fit?

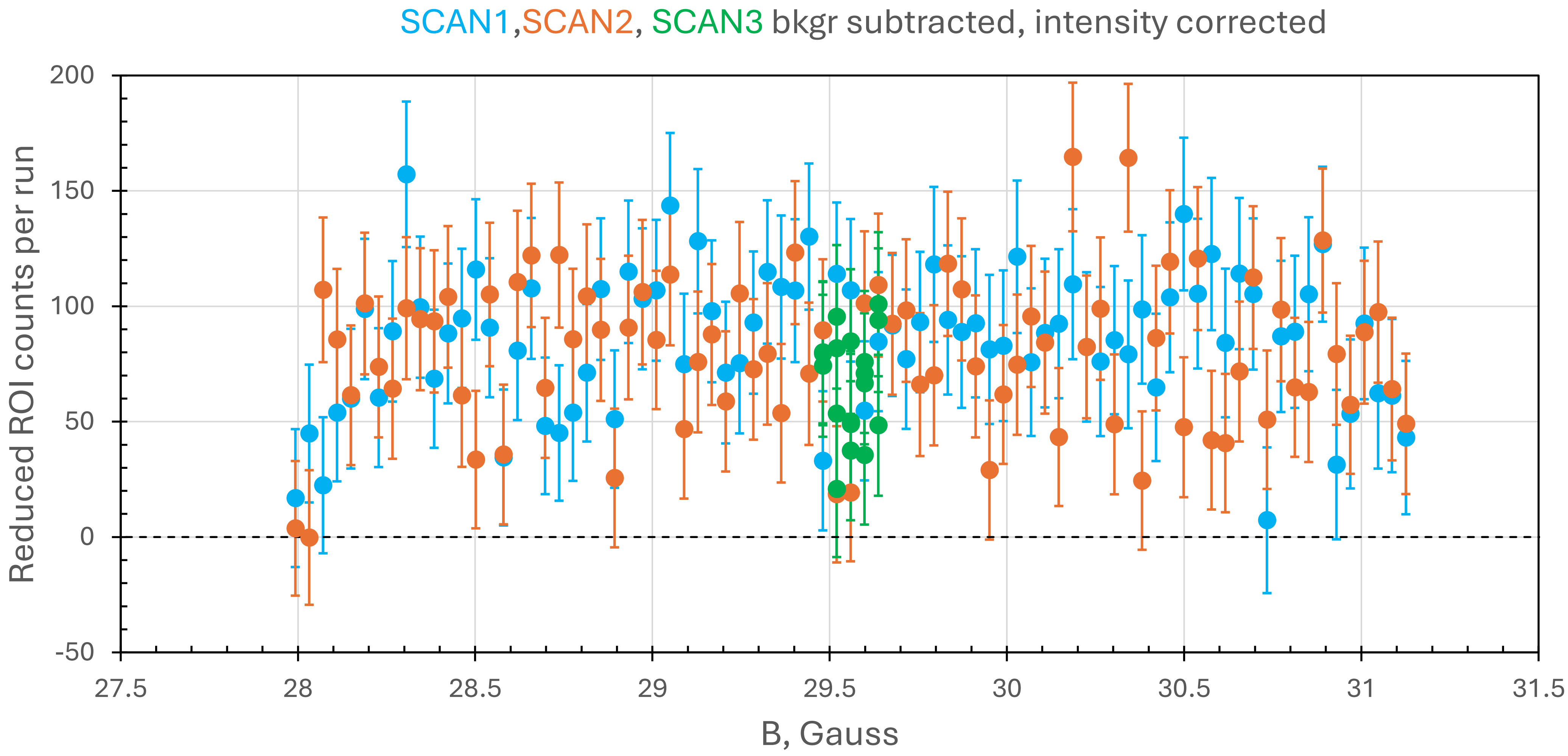
1. ForTMM-related peak should appear around 29.56 Gauss $\pm$ error (to be calculated).
   We can set a limit on $\kappa$ ($n$TMM). Limiting value of $\kappa\mu B$ is >> larger than $\epsilon$ measured in all $n \to n'$ experiment, so, it will be pure case of measurement of $\kappa$. We can use only ~ 5 points centered around 29.56 Gauss and use all other 81-5 points as background. Experience of 2025 data analysis can be used.

2. For following PRD: Using same data we can set 2-dimensional 95% CL parameter exclusion in terms of $(\epsilon, \Delta m)$or $(\kappa, \Delta m)$. With more complicated effort we can set 2-dim limit in terms of $(\epsilon, B')$ or $(\kappa, B')$. Recent PSI published two independent papers (and 2 PhD) $\Delta m$ and $B'$ analysis. We can do it within one PRD paper and Mubi and Linus might include that in their PhD works. UT students can use it for undergraduate theses.

3. Our prototype measurement of shielding factors for mu-metal with corresponding COMSOL analysis can be described in the paper that we submit to NIM. (Evan can lead this effort)

- MM model, in principle, for n has many unknown parameter: $[\epsilon, \kappa(nTMM), \Delta m, B', V_F', V_{B-L}]$
  In principle, suppressing effect of these parameters can be compensated by our magnetic field as $\mu B$

PRELIMINARY



$nn'$ Collaboration meeting September 18, 2026 at ORNL/SNS

# Measurements with $\mu$ prototype at UT

Yuri Kamyshkov

# Goals of $\mu$ Prototype for $n$TMM experiment

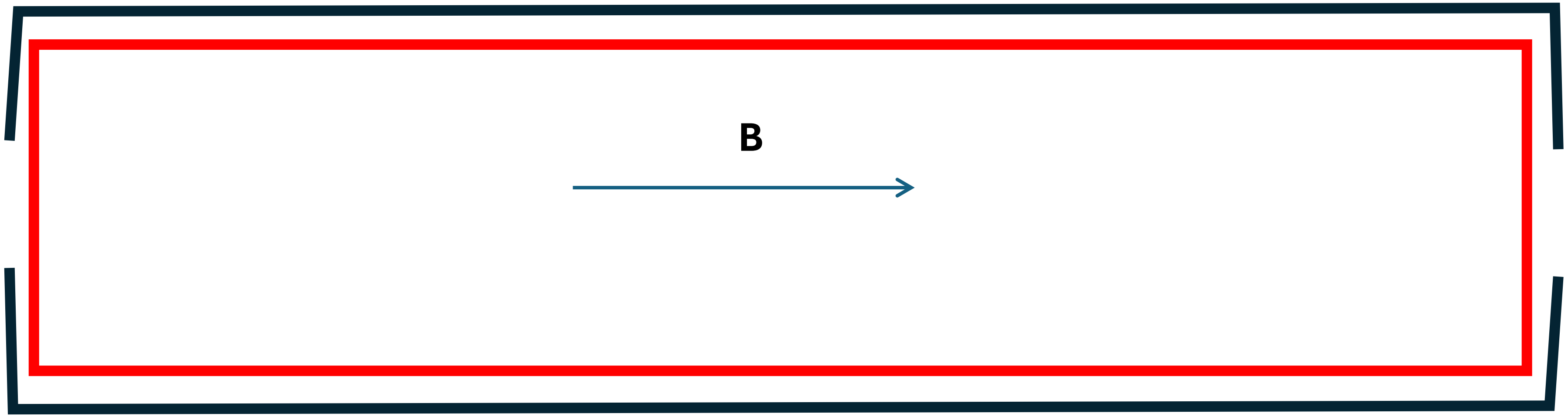
- Confirm that in $n$TMM experiment the magnetic shielding is sufficient for obtaining adjustable UNIFORM magnetic field in both magnets in the presence of external perturbations

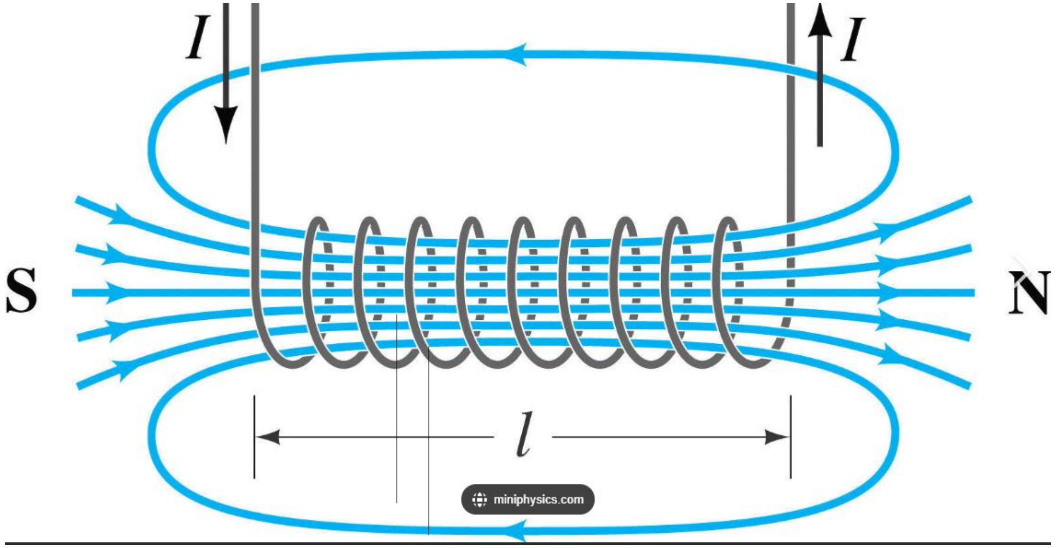
- Width of $n$TMM resonance peak (@ 1.5 atm $CO_2 \approx$ 29.5 Gauss) is ~ 0.15 Gauss; field scanning step is 0.04 Gauss.
  Goal of variation of uniformity under perturbation is 0.01 Gauss

- Thus, max perturbation at GP-SANS 6 Gauss should be shielded with shielding factor S.F. $\gtrsim$ 600

- Lower SF will imply corrections lowering the sensitivity of nTMM

- Effective SF in $n$TMM can be function of solenoidal field due to saturation of the flux in mu-metal of internal shield. This should be addressed in prototype tests.


B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S
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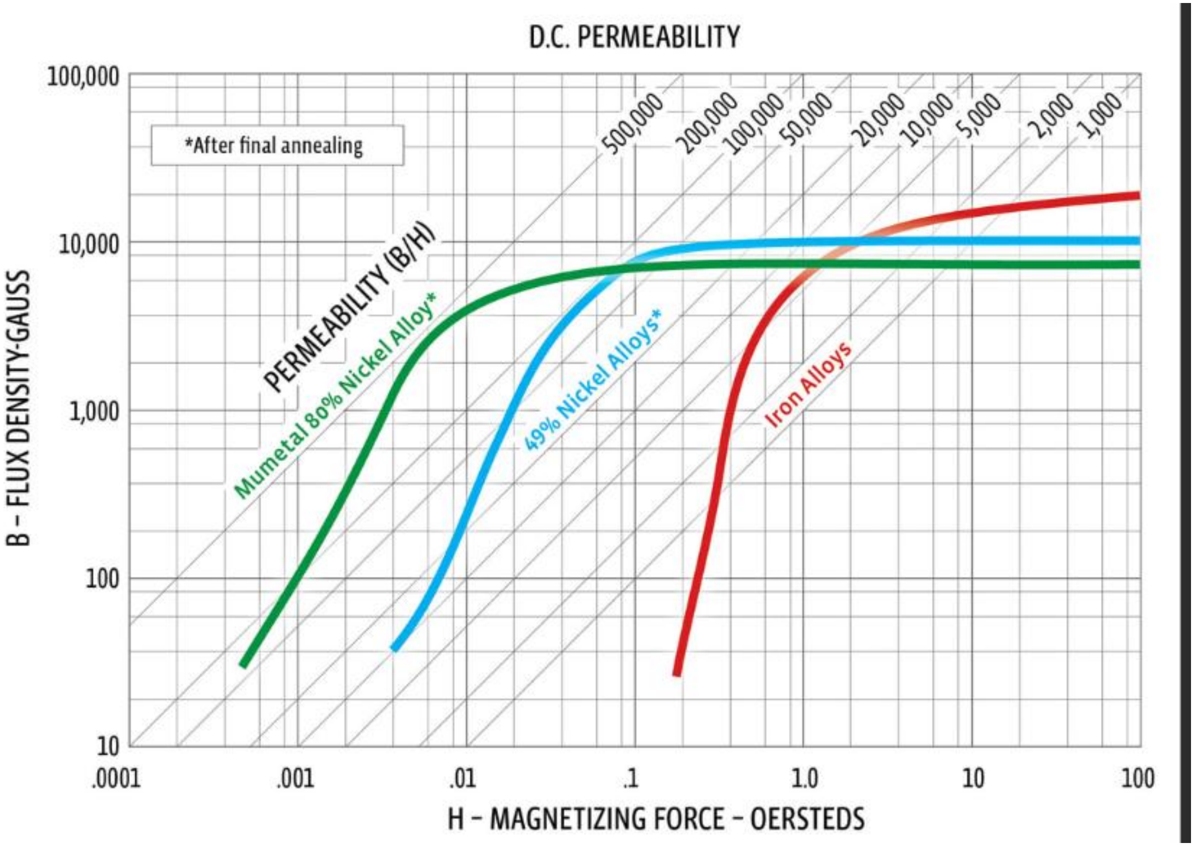
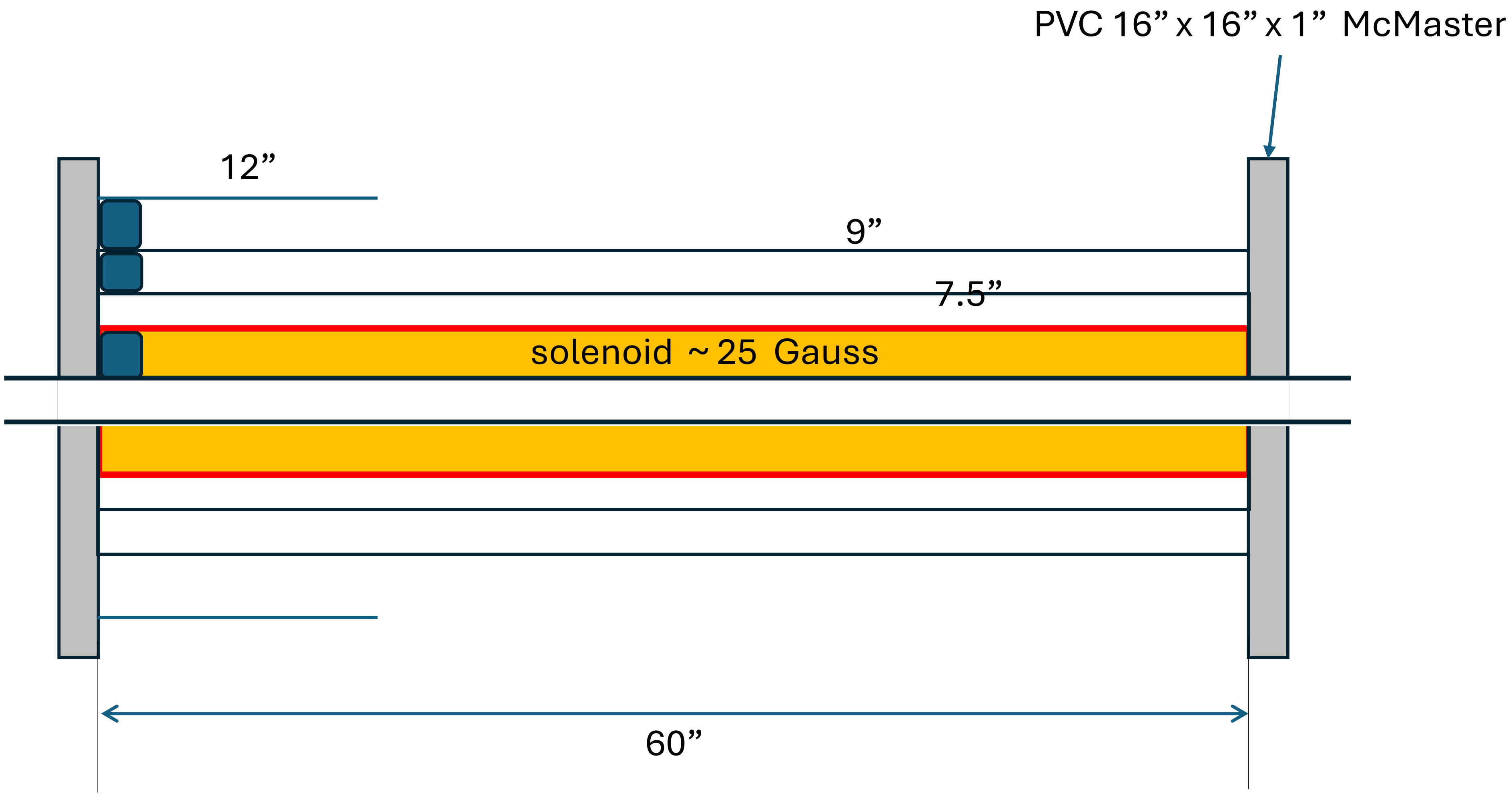
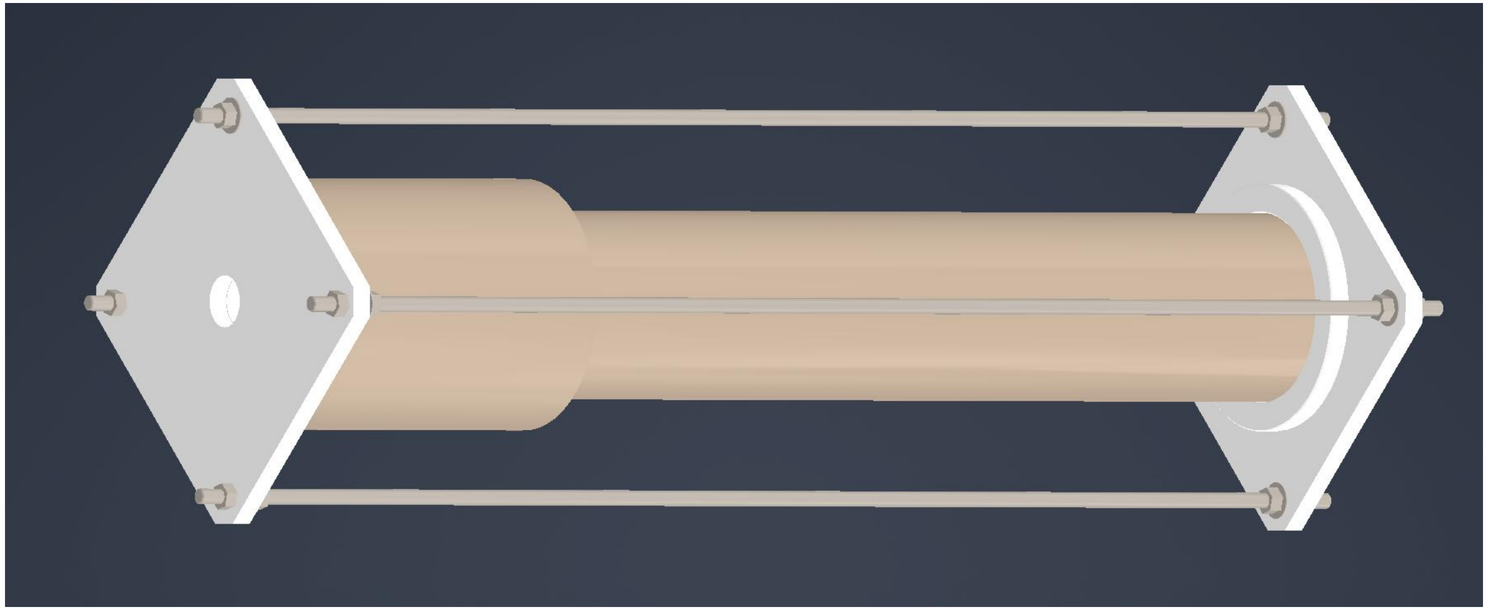
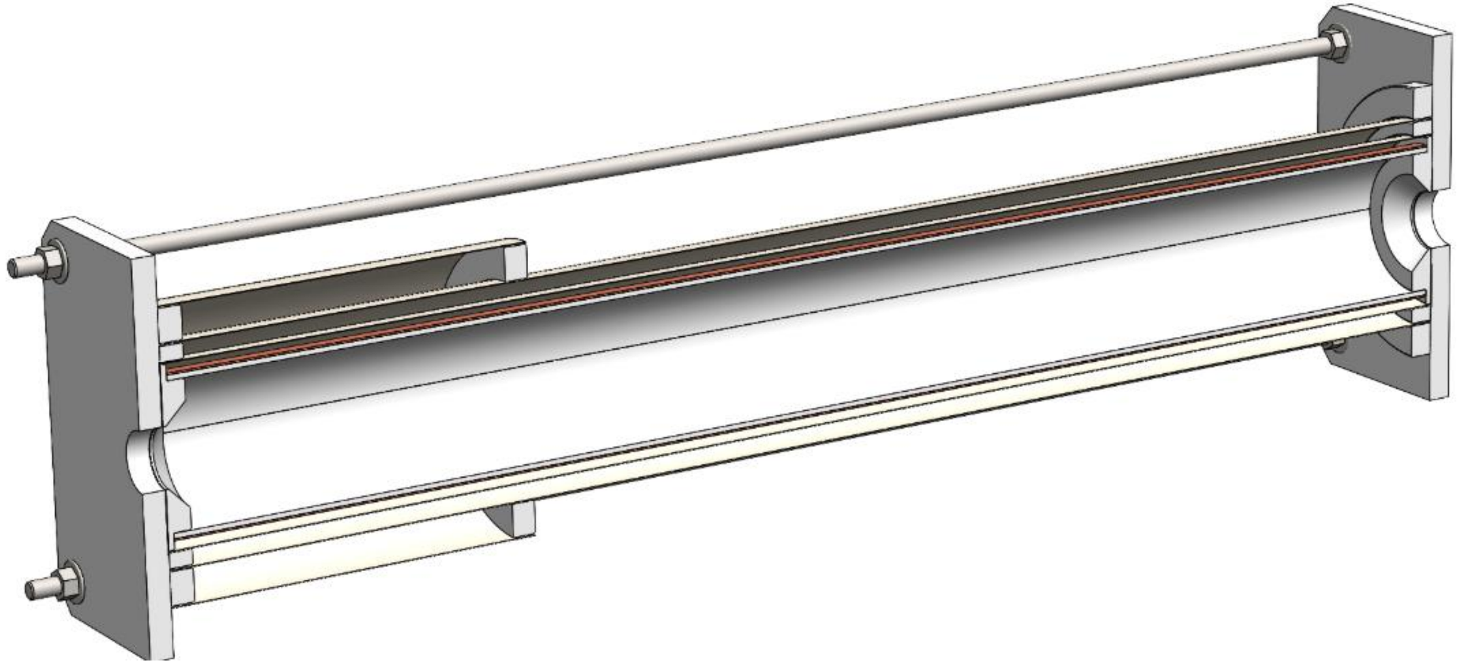
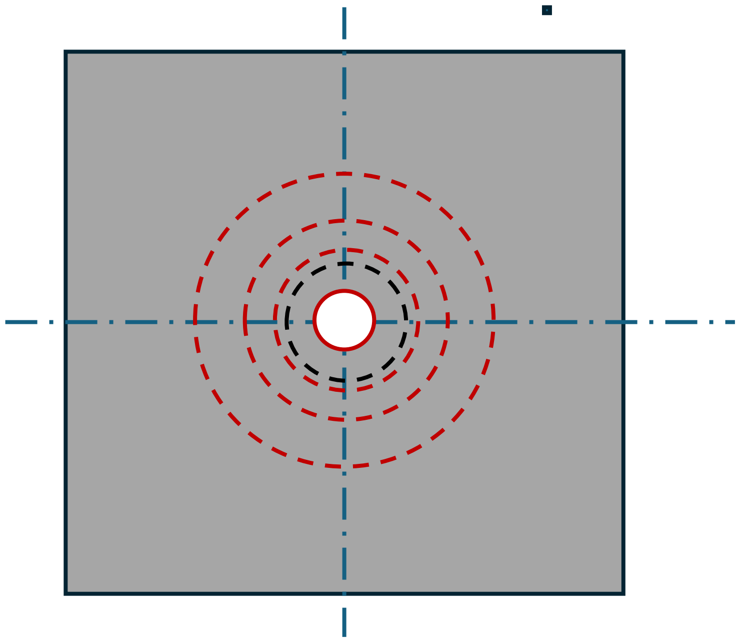
miniphysics.com

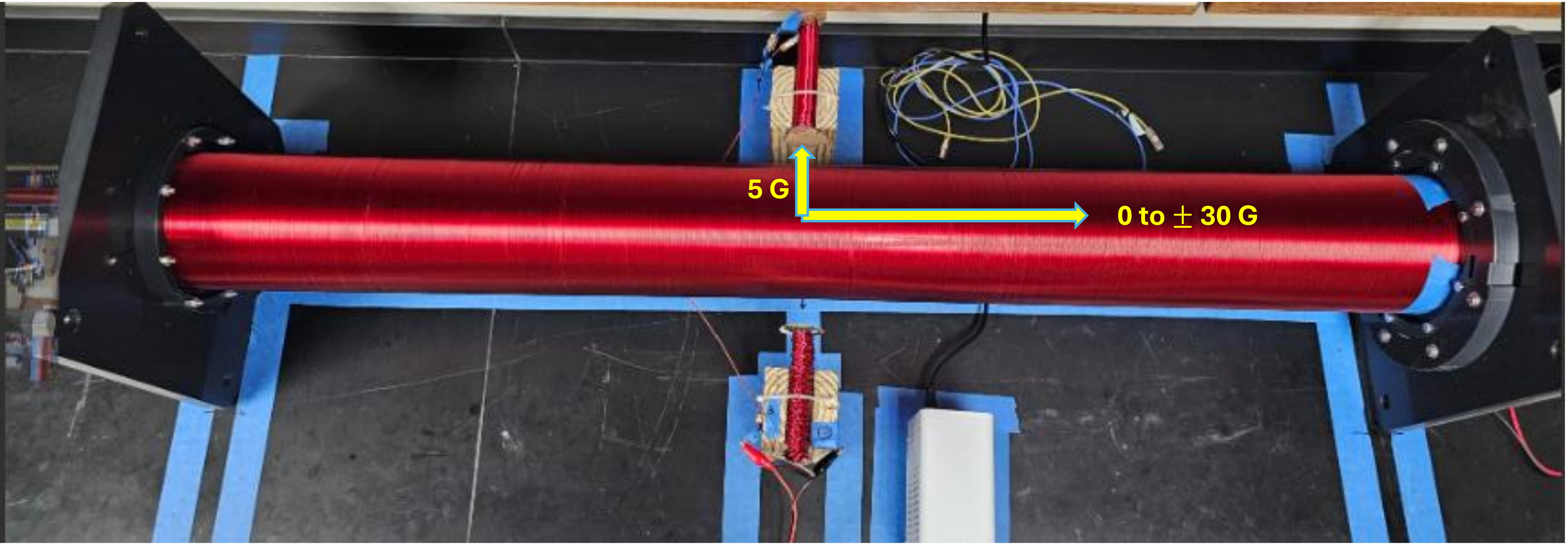

D.C. PERMEABILITY
*After final annealing
PERMEABILITY (B/H)
500,000
200,000
100,000
50,000
20,000
10,000
5,000
2,000
1,000
Mumetal 80% Nickel Alloy*
49% Nickel Alloys*
Iron Alloys
100,000
10,000
1,000
100
10
B – FLUX DENSITY-GAUSS
.0001
.001
.01
.1
1.0
10
100
H – MAGNETIZING FORCE – OERSTEDS

# Schematic of $\mu$-prototype



June 15, 2026

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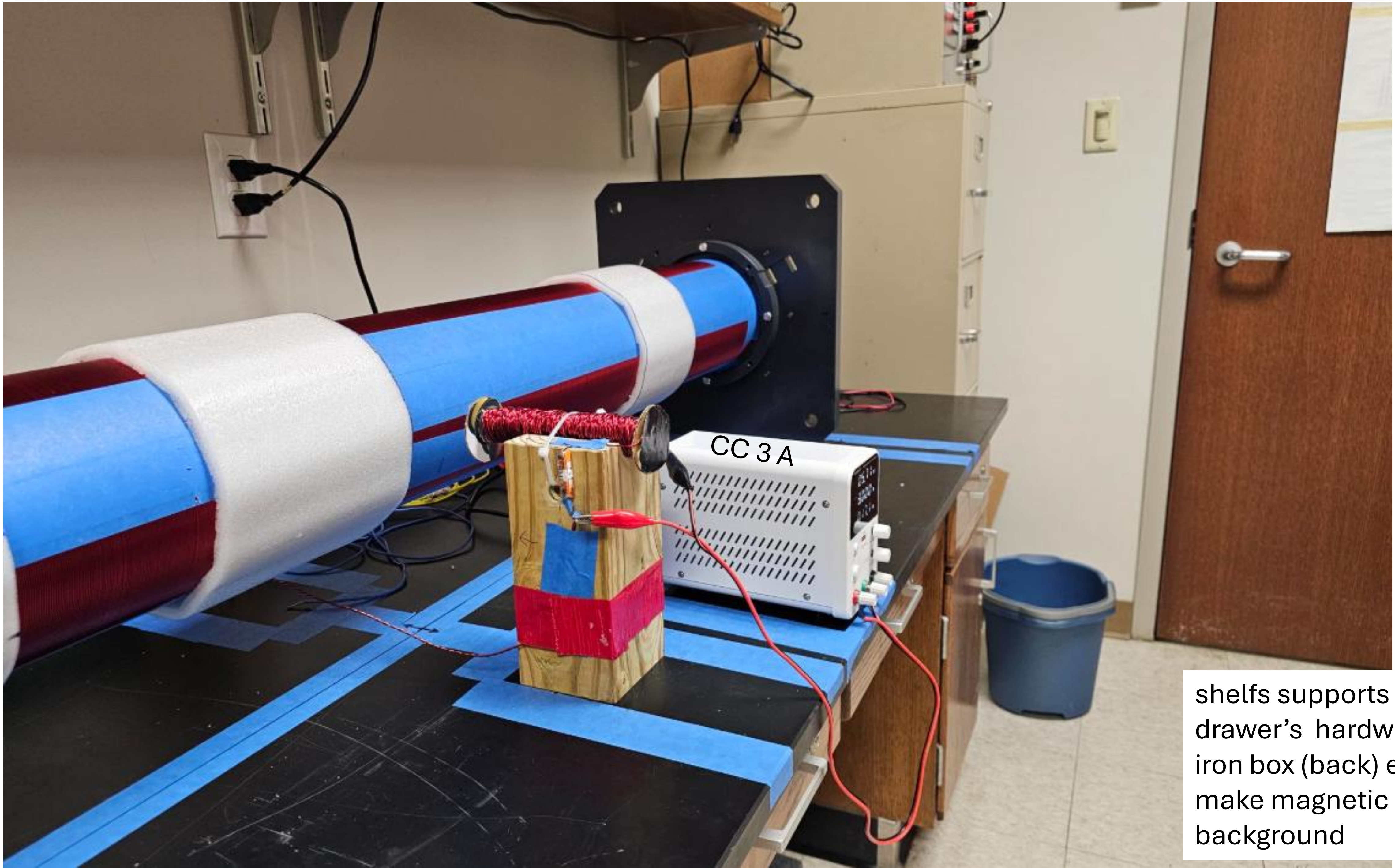
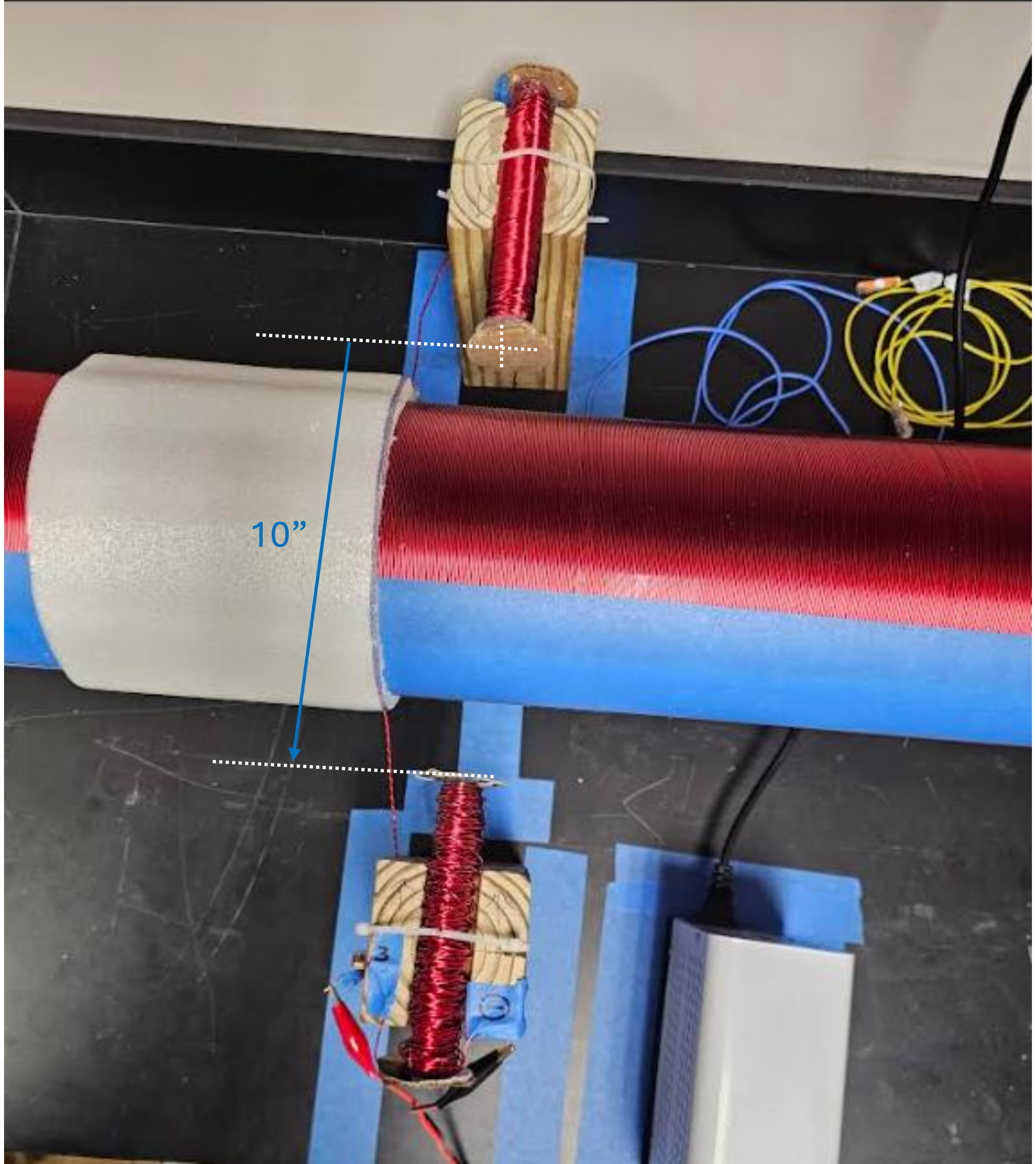
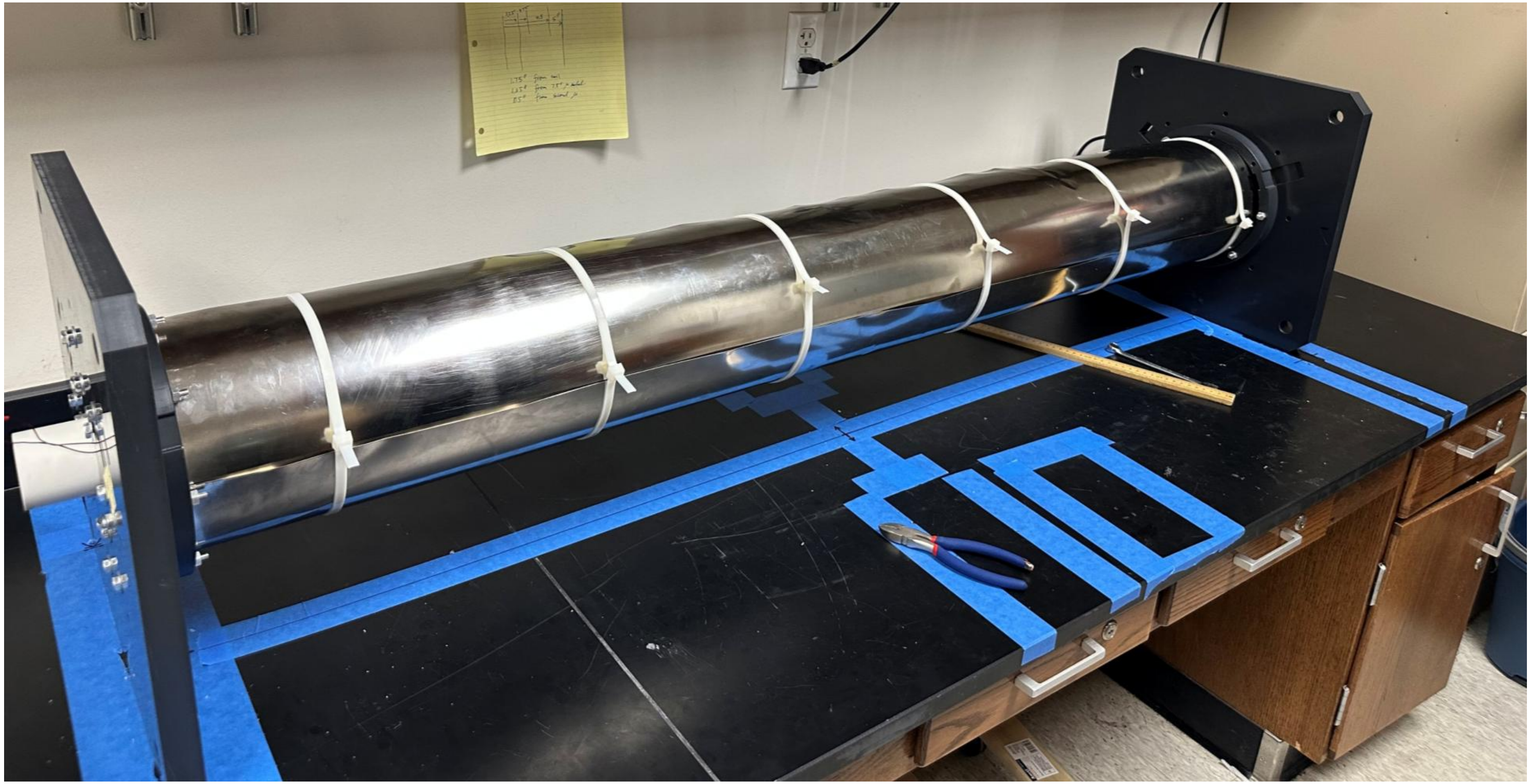


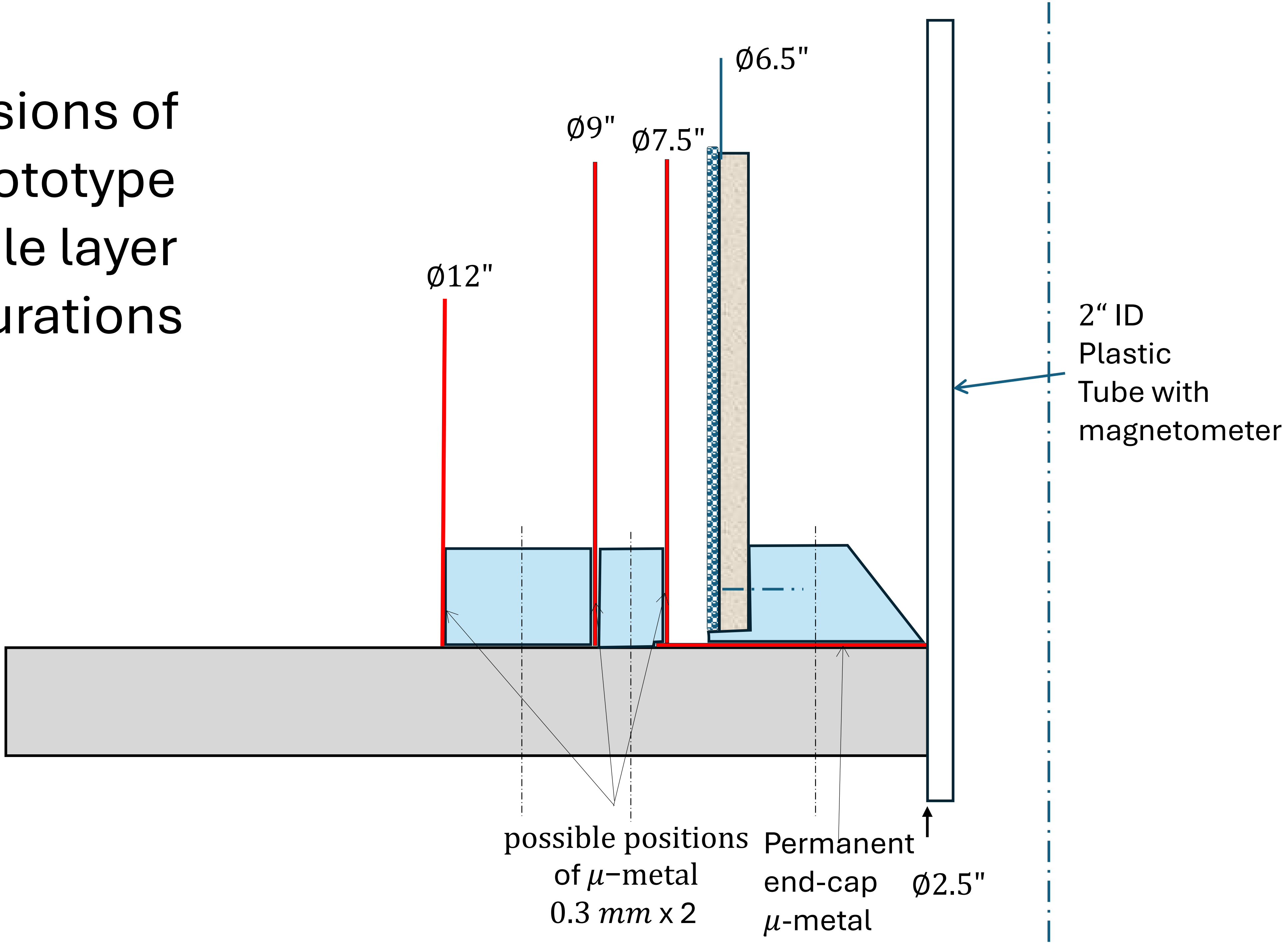

shelfs supports drawer’s hardware, iron box (back) etc. make magnetic background



10”



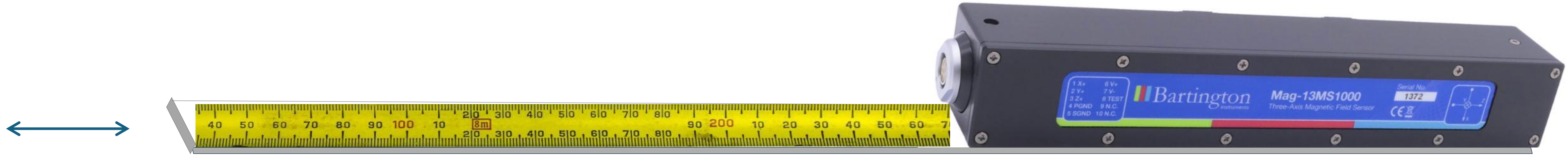
# Dimensions of mu-prototype possible layer configurations



# It was designed for

## Bartington Flux-gate 3D sensor with Spectromag-6 DAQ system

## Mag-13MS1000 with range $\pm 1000 \mu T$ ( $\pm$10 Gauss )



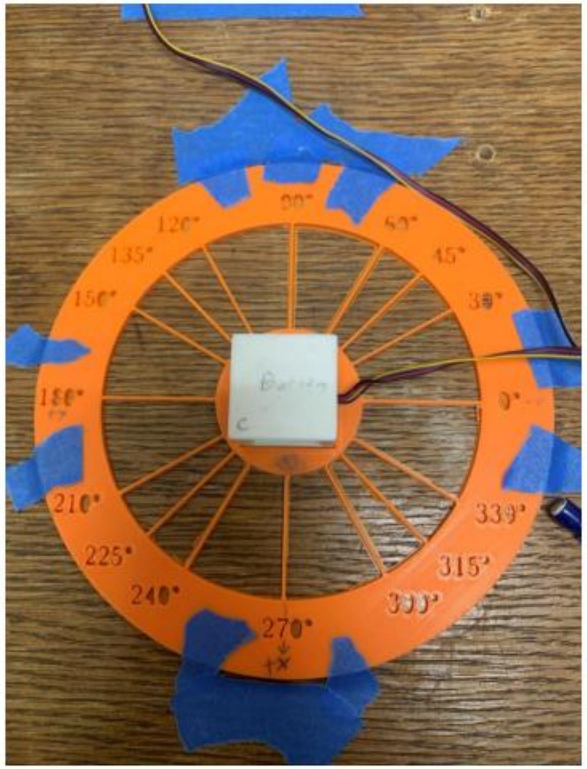

Aluminum bar~ 70” long

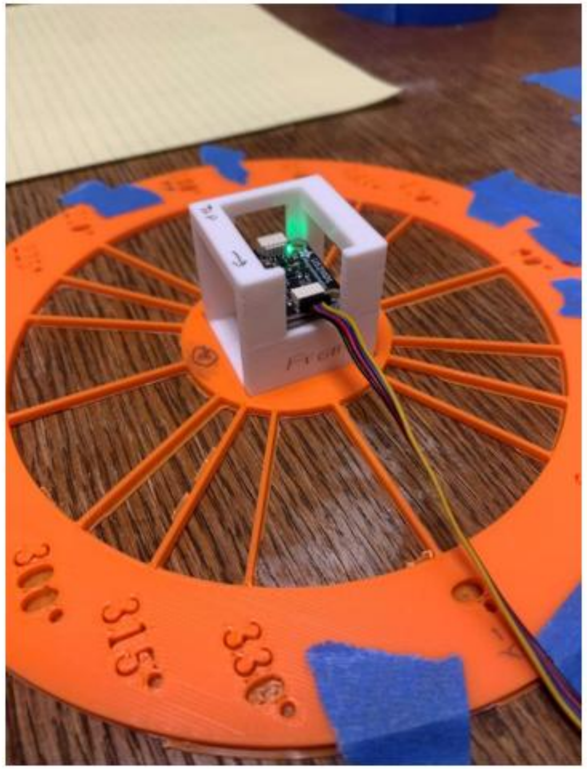
1.25” x 1.25” x 6”

Limitations: Short range of measurement <10 G, distortion of B-readings if one of sensors is saturated at high field; no temperature control

# Alternative chip magnetometer LIS2MDL with range $\pm 50$ Gauss

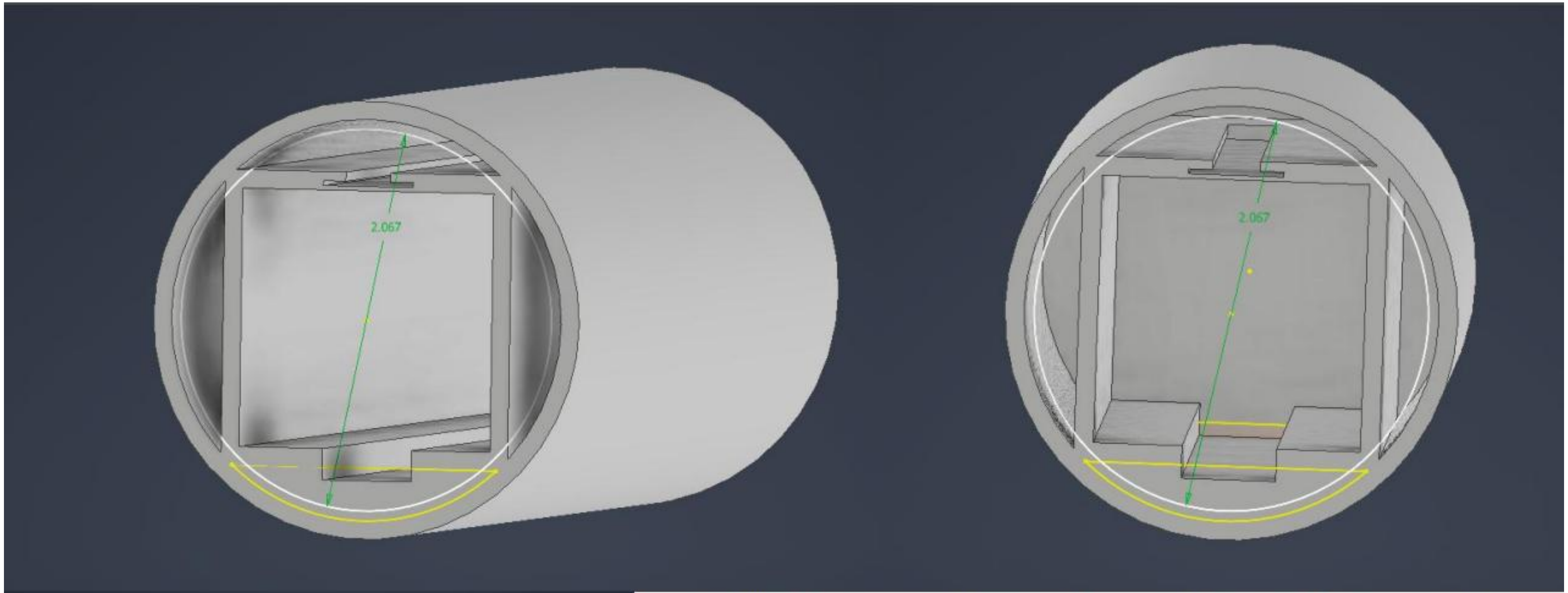
Challenges: in control of alignment (angle $B_x/B_z$). **Essential temperature dependence.** Introduced thermocouples and compressed air flow in the guide tube to maintain thermal equilibrium in field measurements.

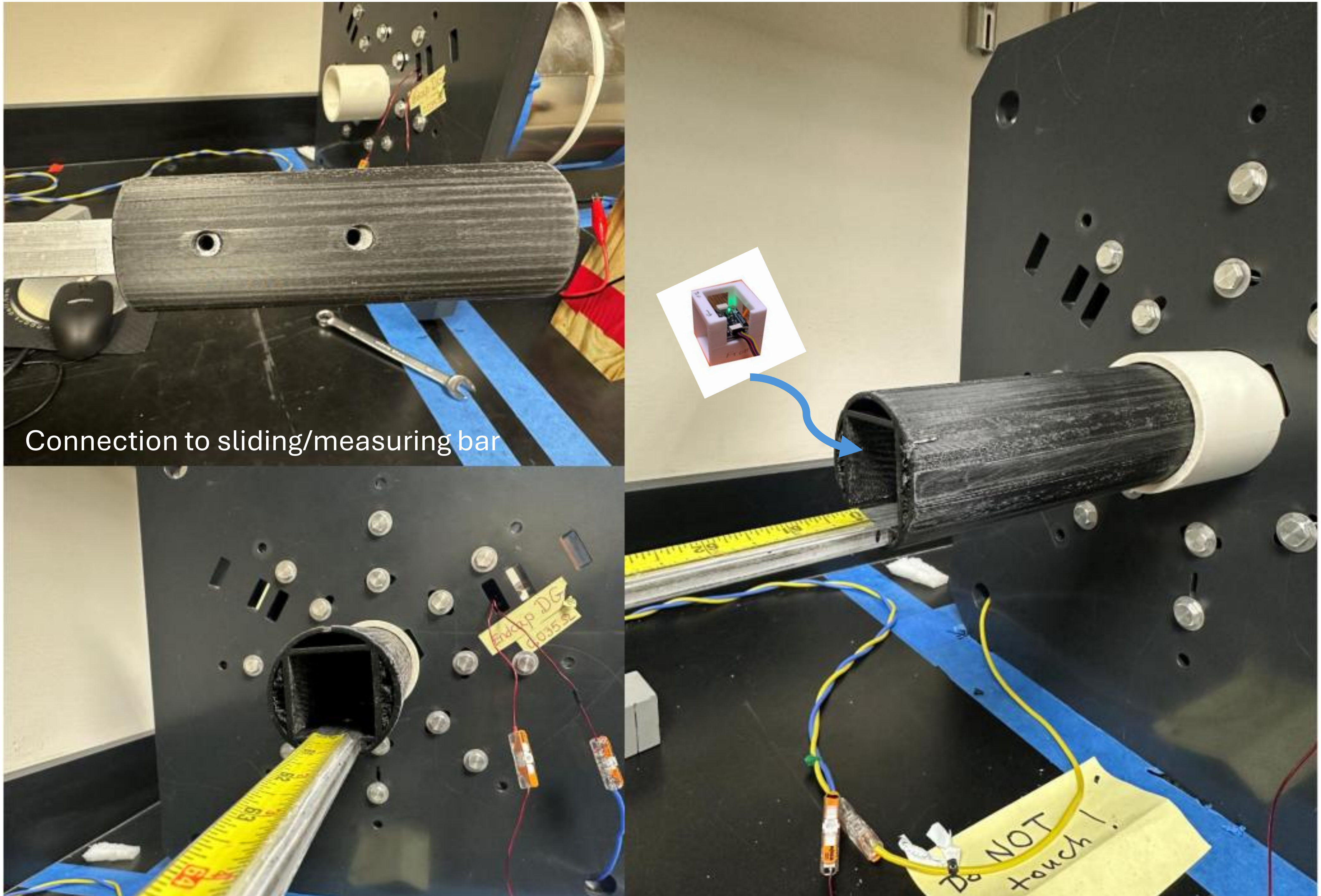


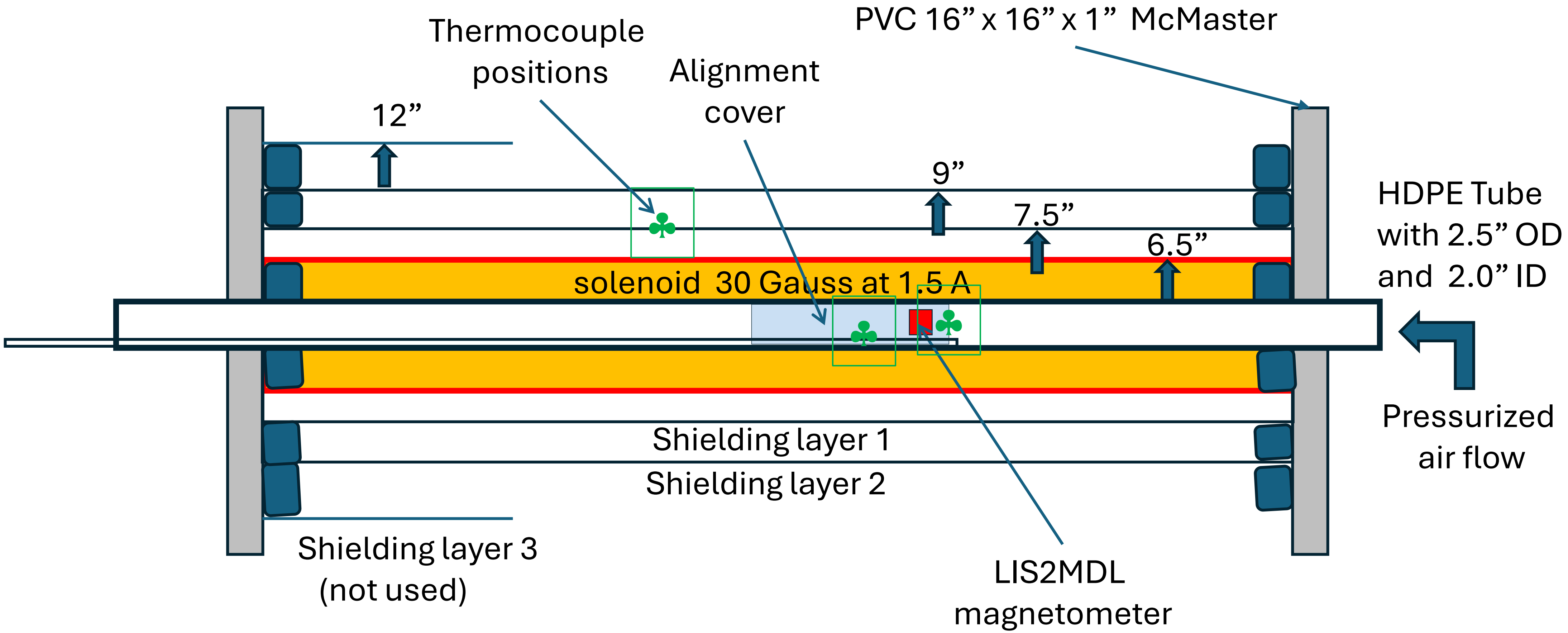
LIS2MDL inside the box with the side 1.25”

# 3D printer model of magnetometer housing




- Cylindrical with minimal tolerance to prevent freedom of movement, slots into current PVC tube
- Slot for Bartington MAG, cut-out for metal guidance rod (need to add slot for screws on bottom of rod)
- Groove on top of outer radius, will catch screws connected to current PVC tube and prevent rotation (to be implemented)
- Suggestions?
- Connor Cambria developing similar brace for his custom magnetometer to be used in future measurements

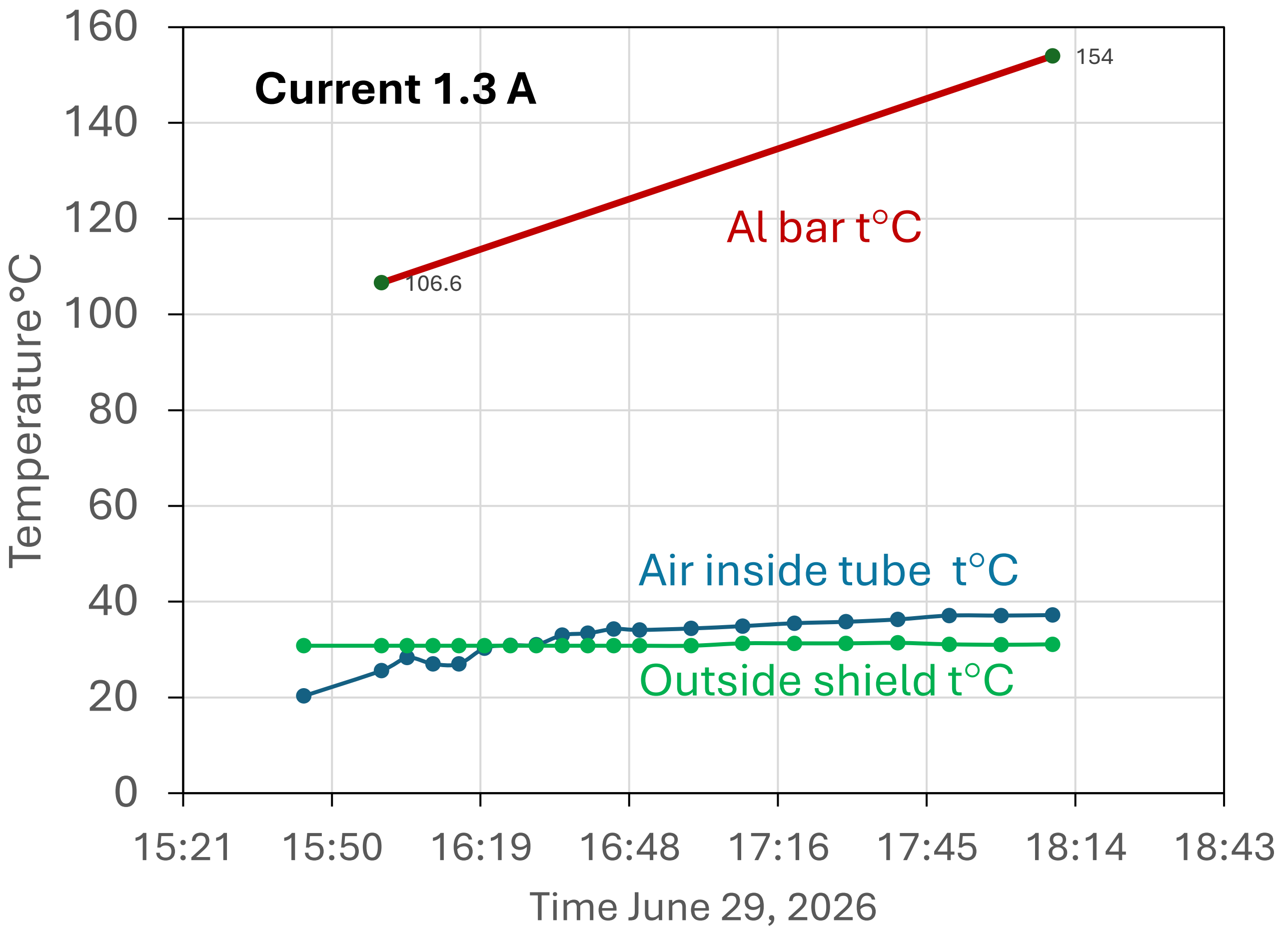

Connection to sliding/measuring bar
Do NOT touch!



Thermocouple positions
PVC 16" x 16" x 1" McMaster
Alignment cover
12"
9"
7.5"
6.5"
HDPE Tube with 2.5" OD and 2.0" ID
solenoid 30 Gauss at 1.5 A
Pressurized air flow
Shielding layer 1
Shielding layer 2
Shielding layer 3 (not used)
LIS2MDL magnetometer

At high coil currents, 1.3A (~ 26 G field) dissipated power is ~ 47 W.
Inside the plastic measurement tube temperature  can substantially increased

Configuration : inner mu-shielding is 0.6 mm, chip magnetometer in the center of coil z=88”

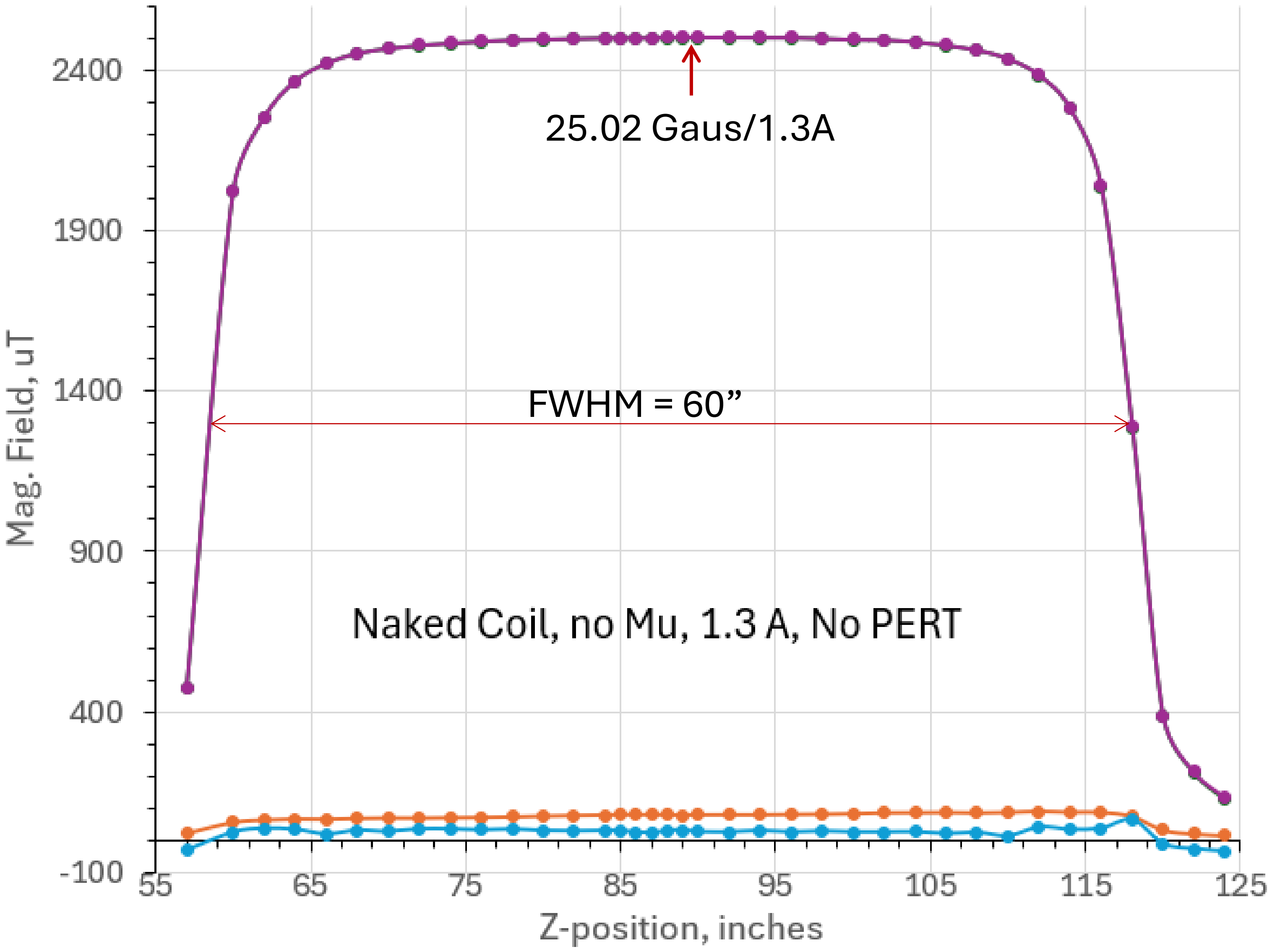



Forced air colling flow inside the tube is mandatory

- When previously we used 10-Gauss Bartington magnetometer  (0.5 A) power dissipation was ~ 10 times lower. Now we perform all measurements with chip magnetometer and field 25 Gauss.
- With high current operation longitudingal position scan are not reliable even with air flow cooling due to temperature variation along z

# Naked Coil 3 field components, no mu-metal, no PERT

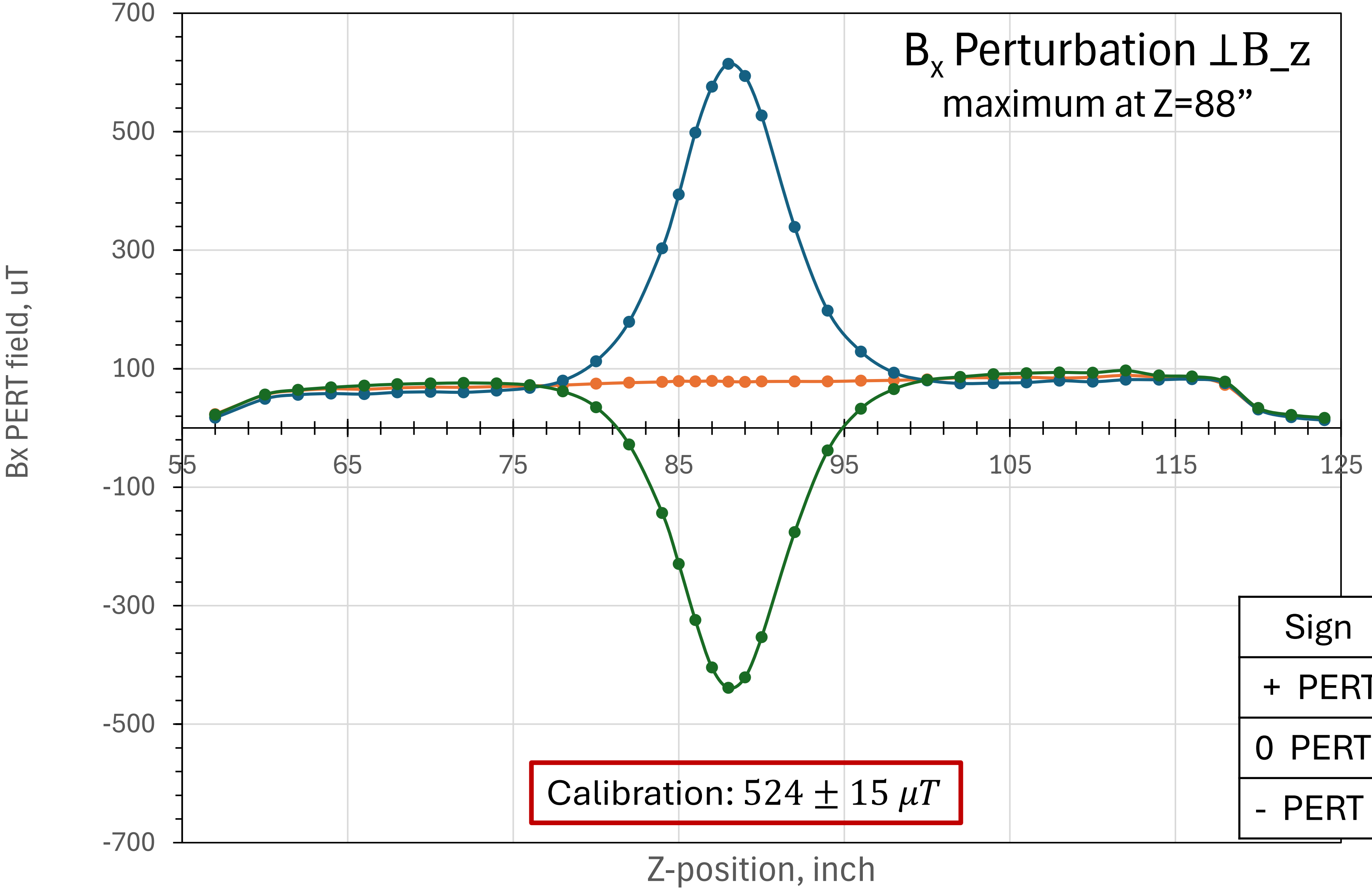
June 12,2026




mu-metal endcaps are installed

June 12,2026

# Naked Coil, with PERT, Coil current 1.3 A

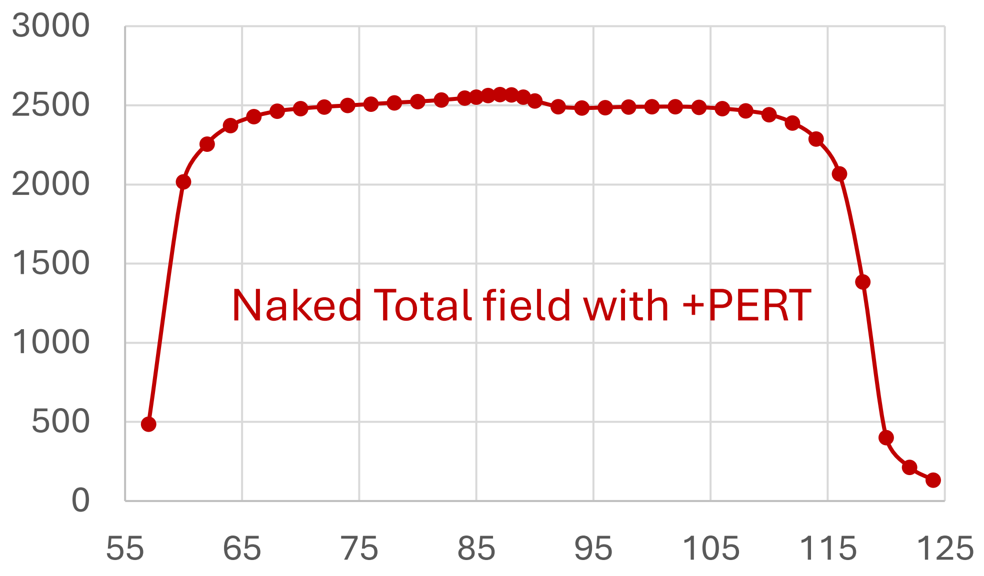


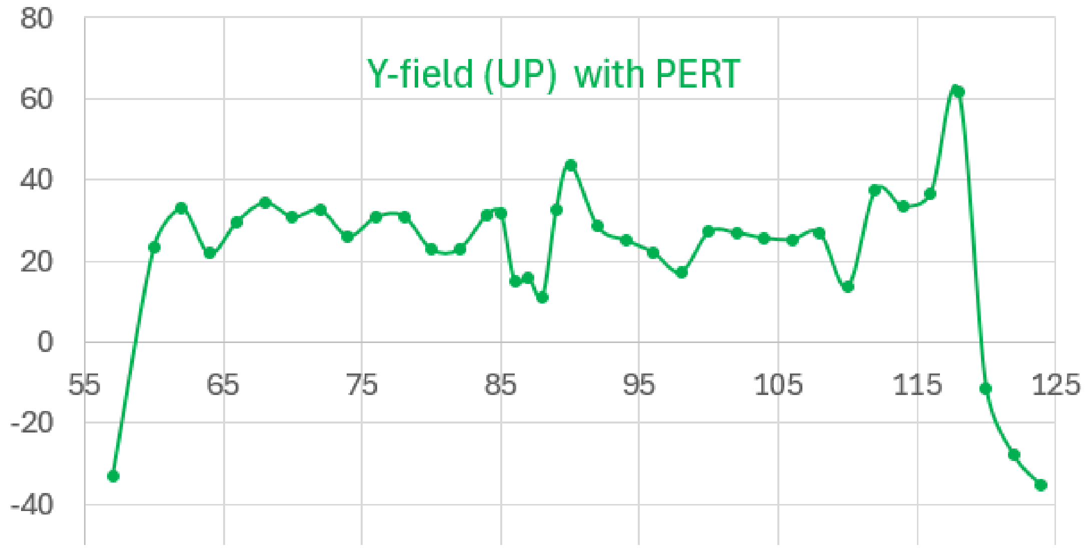

| Sign | $Bx$ (88") |
|---|---|
| + PERT | $614.4\ \mu T$ |
| 0 PERT | $78.2\ \mu T$ |
| - PERT | $-438.9\ \mu T$ |

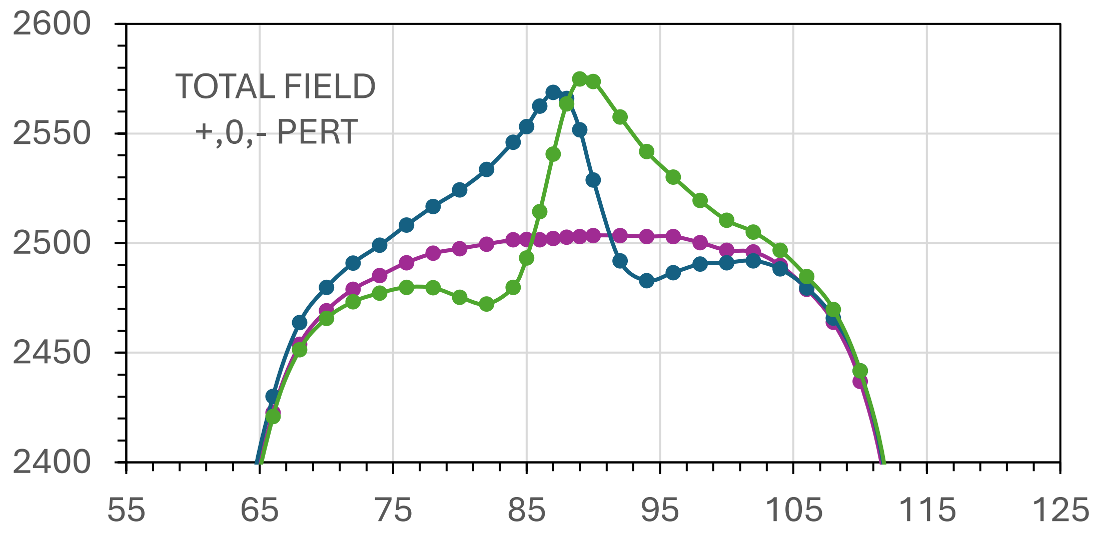
By PERT current inversion

# Naked Coil with current 1.3 A and PERT

June 12,2026




Two perturbation magnets are slightly misaligned

# In General:

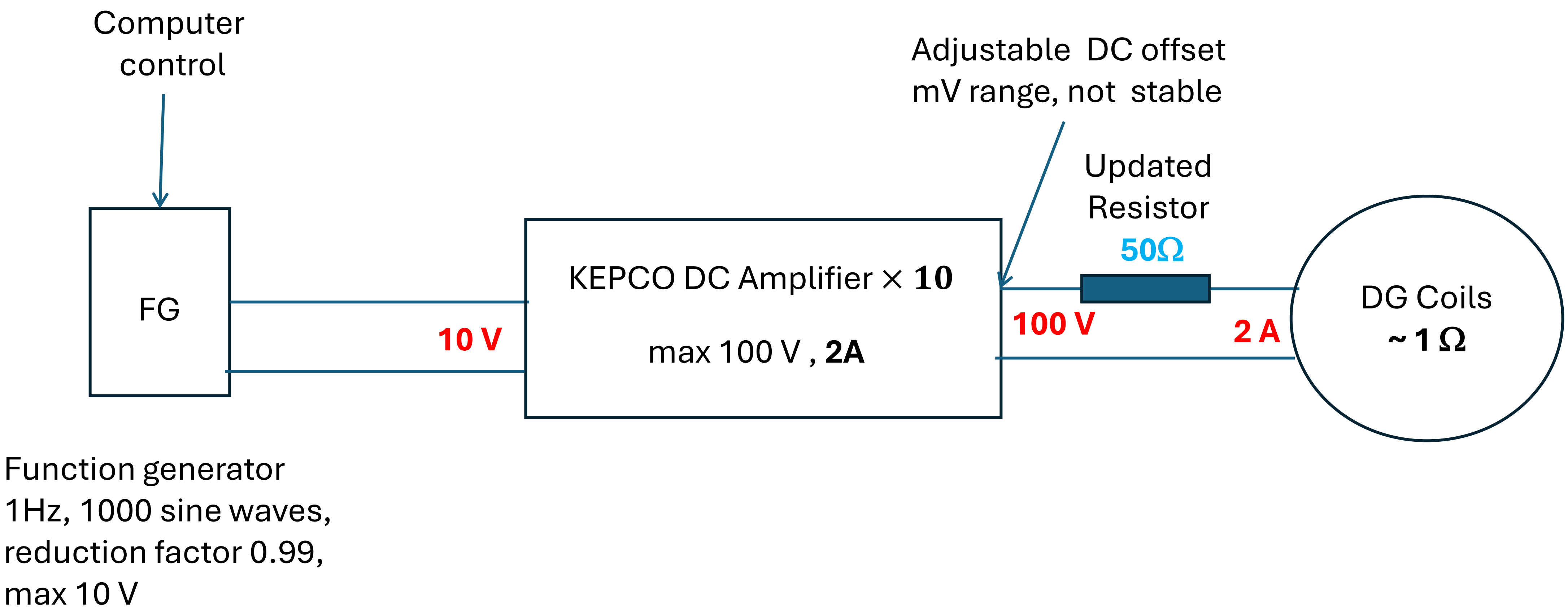
- Longitudinal scans along z with magnet ON are subject of temperature variation of readings

- Air blowing through the guide tube improves the t-variation, however, needs time for thermalization

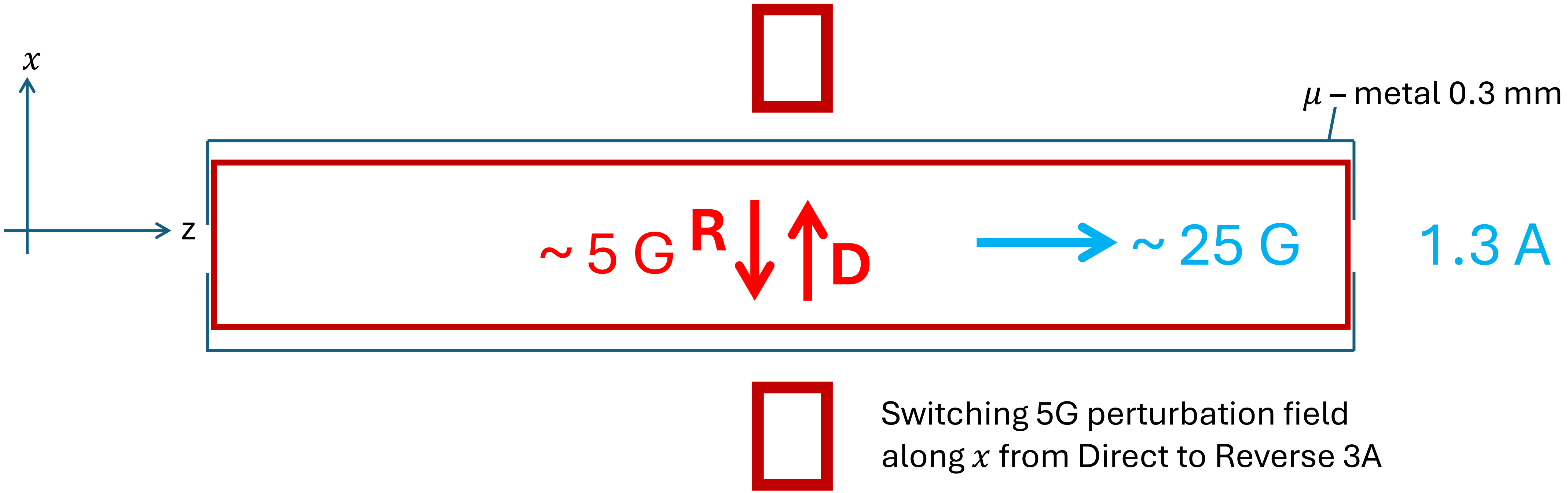
- Best compensation of t-dependence can be reached when magnetometer is at fixed z-position  (88” – peak position) and air-cooled for long time for equilibrium setting.

- In this case, if coil current variation/measurements are quick; effect of temperature variation is small.

# Scheme of degaussing DG

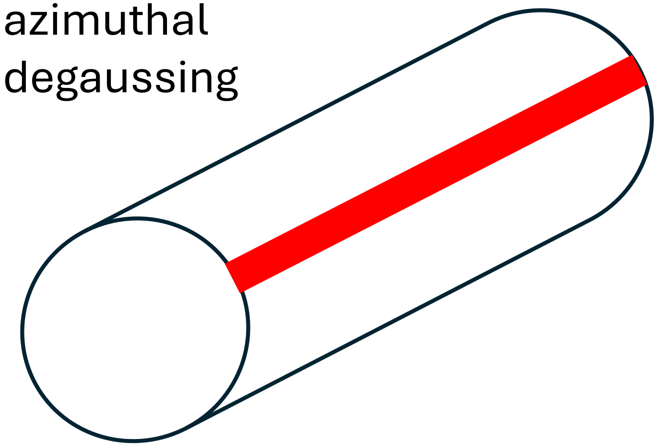


3 degaussing circuits (cylinder and endcaps) serially connected with total resistance ~ 1 Ω

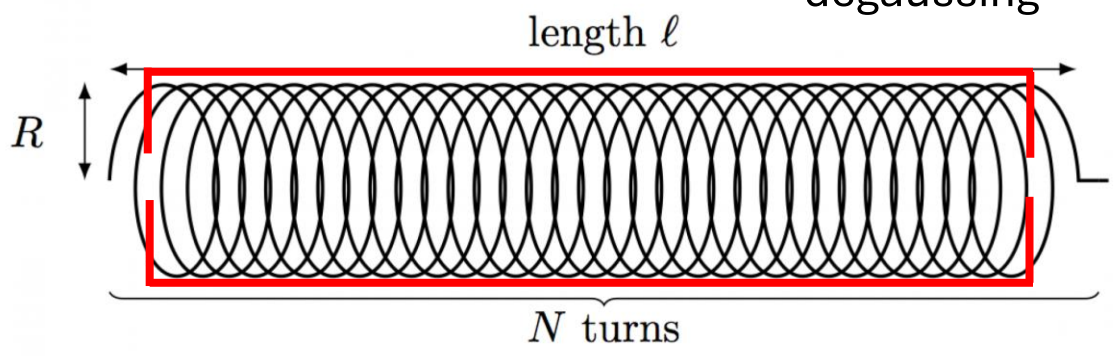


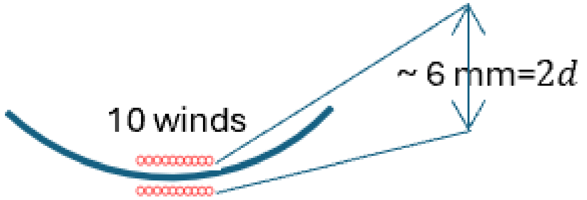
# Degaussing in mu-prototype at UT

azimuthal degaussing



longitudinal degaussing




Max degaussing current $= \frac{100V}{50\Omega} = 2A$

$$B = 10 \times \mu_0 \frac{I}{\pi d} = 26.7 \times 10^{-4} T = 26.7\ Oe \rightarrow \ 0.76\ T$$

Max azimuthal field in mu-metal

$$\mathrm{R} = 6.5''/2 = 82.6\ \mathrm{mm}$$

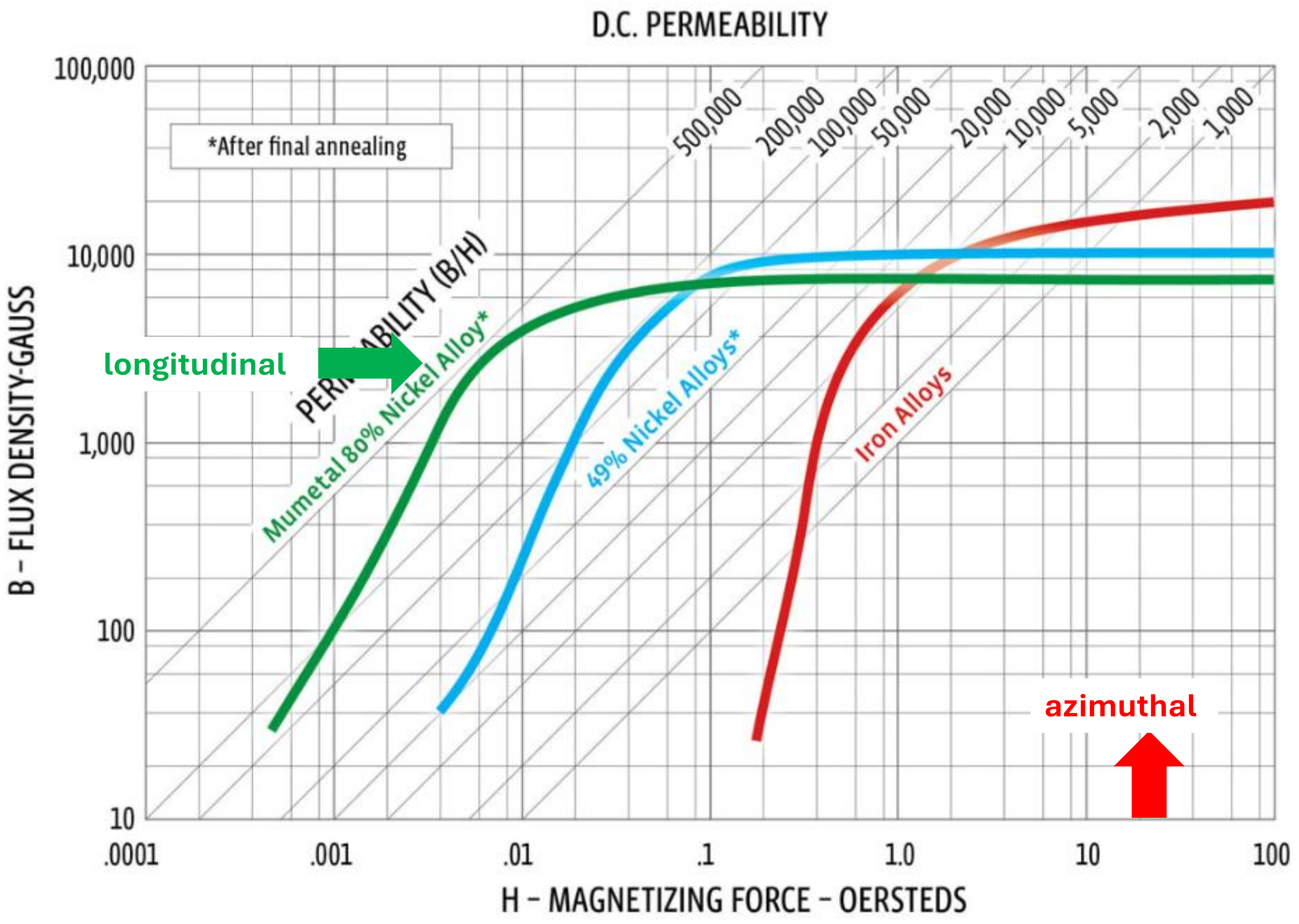
$$\Phi = B \cdot A = 25G \cdot \pi \cdot (82.6)^2 \cong$$

$$\cong\ B_\mu \cdot 2\pi \cdot (82.6) \cdot 0.46$$

Magnetic field inside mu-metal

$$B_\mu(max) = 0.23\ T$$

Max longitudinal field in mu-metal



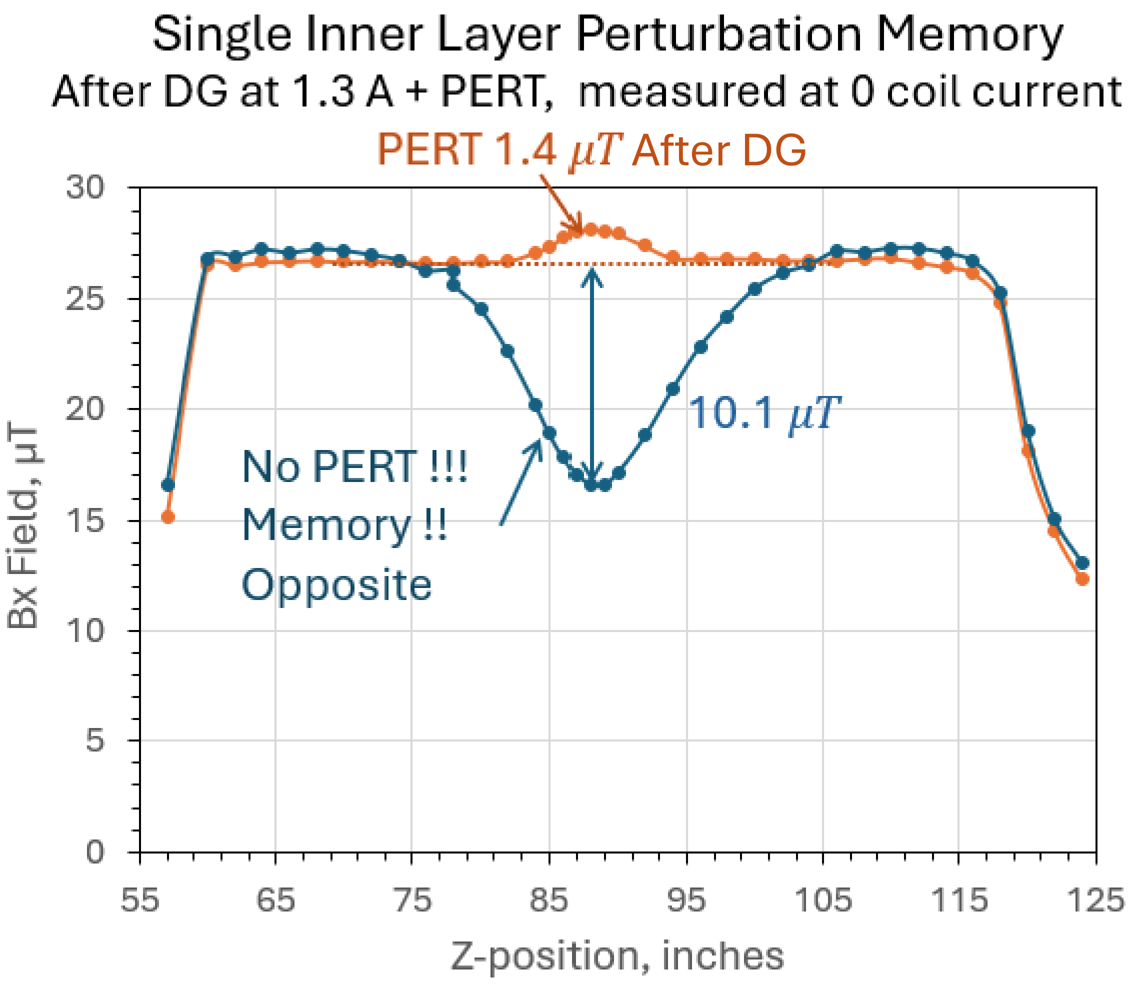
D.C. PERMEABILITY
*After final annealing
100,000
10,000
1,000
100
10
.0001
.001
.01
.1
1.0
10
100
B – FLUX DENSITY-GAUSS
H – MAGNETIZING FORCE – OERSTEDS
500,000
200,000
100,000
50,000
20,000
10,000
5,000
2,000
1,000
PERMEABILITY (B/H)
Mumetal 80% Nickel Alloy*
49% Nickel Alloys*
Iron Alloys
longitudinal
azimuthal

- Degaussing of mu-metal should be performed with the magnet and perturbation state close to operational !

- Our standard mode of degaussing was with + PERT and coil 1.3 A

- By degaussing the shielding remembers the perturbation with opposite sign →

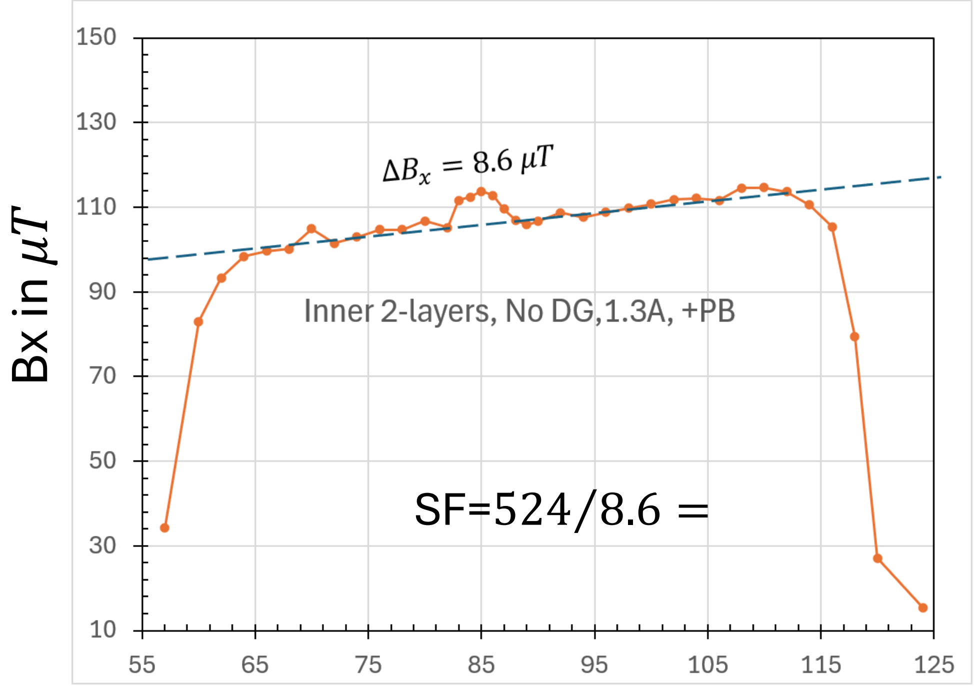
- For Shielding Factor measurement it was important to set magnetometer position on the peak of PERT



# Two methods of perturbation measurement in the presence of $\mu$ shield:

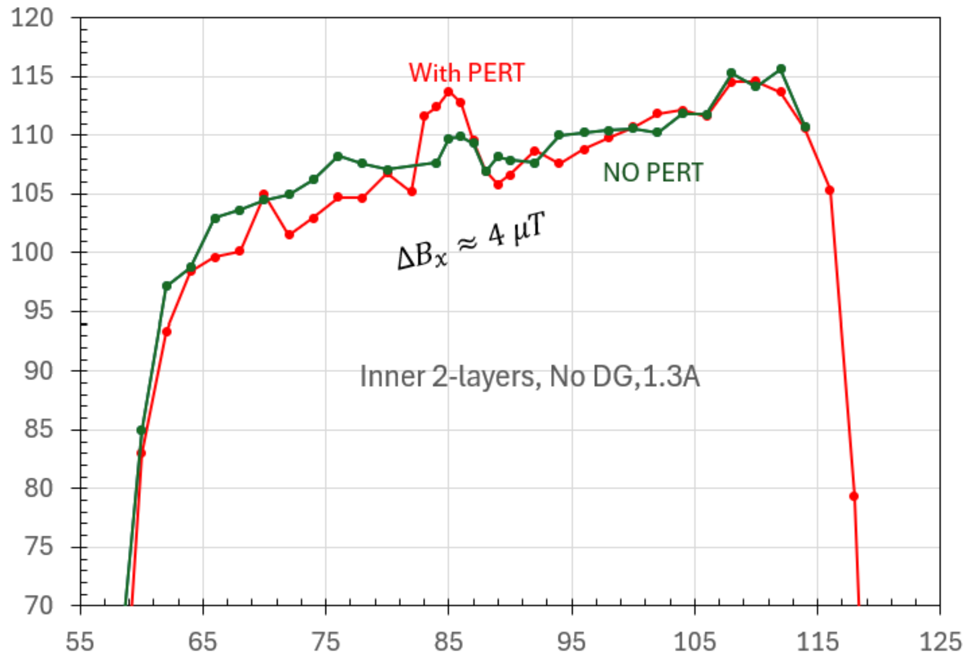
1 Based on z-scan

1a




Magnetometer z-position, inch

1b

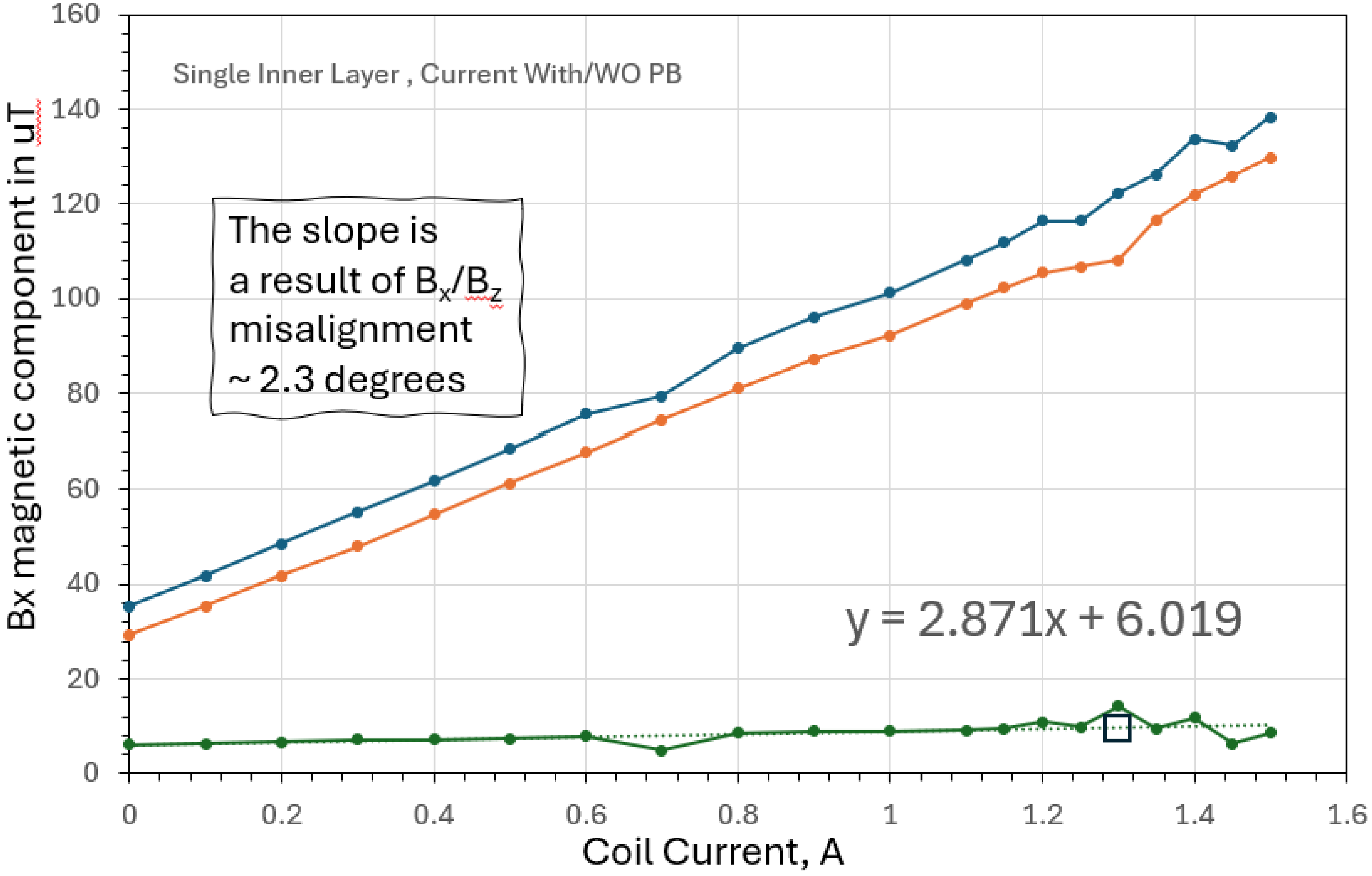



Magnetometer z-position, inch

- Slope due to temperature distribution along the tube
- With Air flow present

2

Magnetometer z-positioned at the peak of perturbation.
Thermal equilibrium reached with Air flow at coil current 1.3 A
Quick variation of coil current from 0 A to 1.5 A with and without PERT.
Perturbation signal is measured at 1.3 A



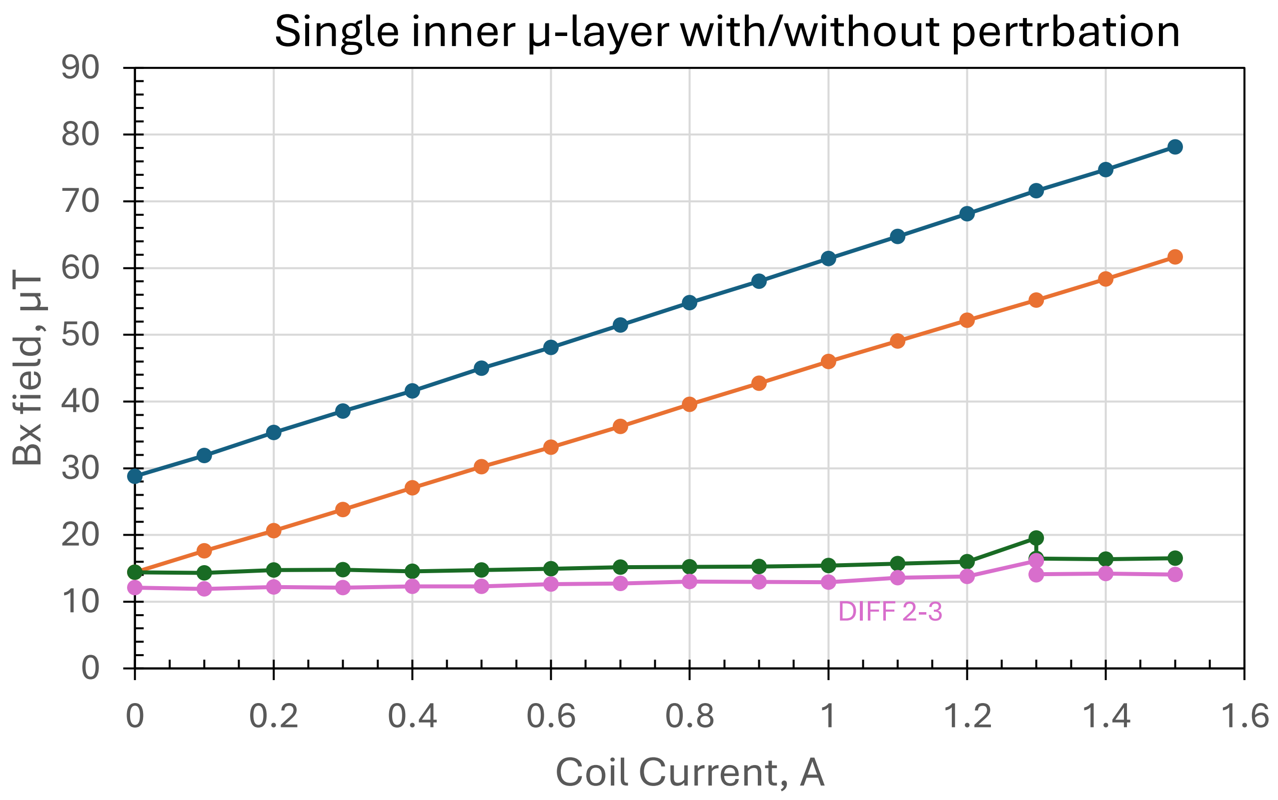

Shielding factor at I=1.3 A
$SF_1$=524/9.75=**53.7**

Method 2 seems more reliable

# 1 μ - inner layers

- Major question was how shielding factor will change with the saturation of mu-metal serving as flux return yoke of the solenoid.

Standard degaussing, $B_x$ field with/without perturbation at z peak position 88”



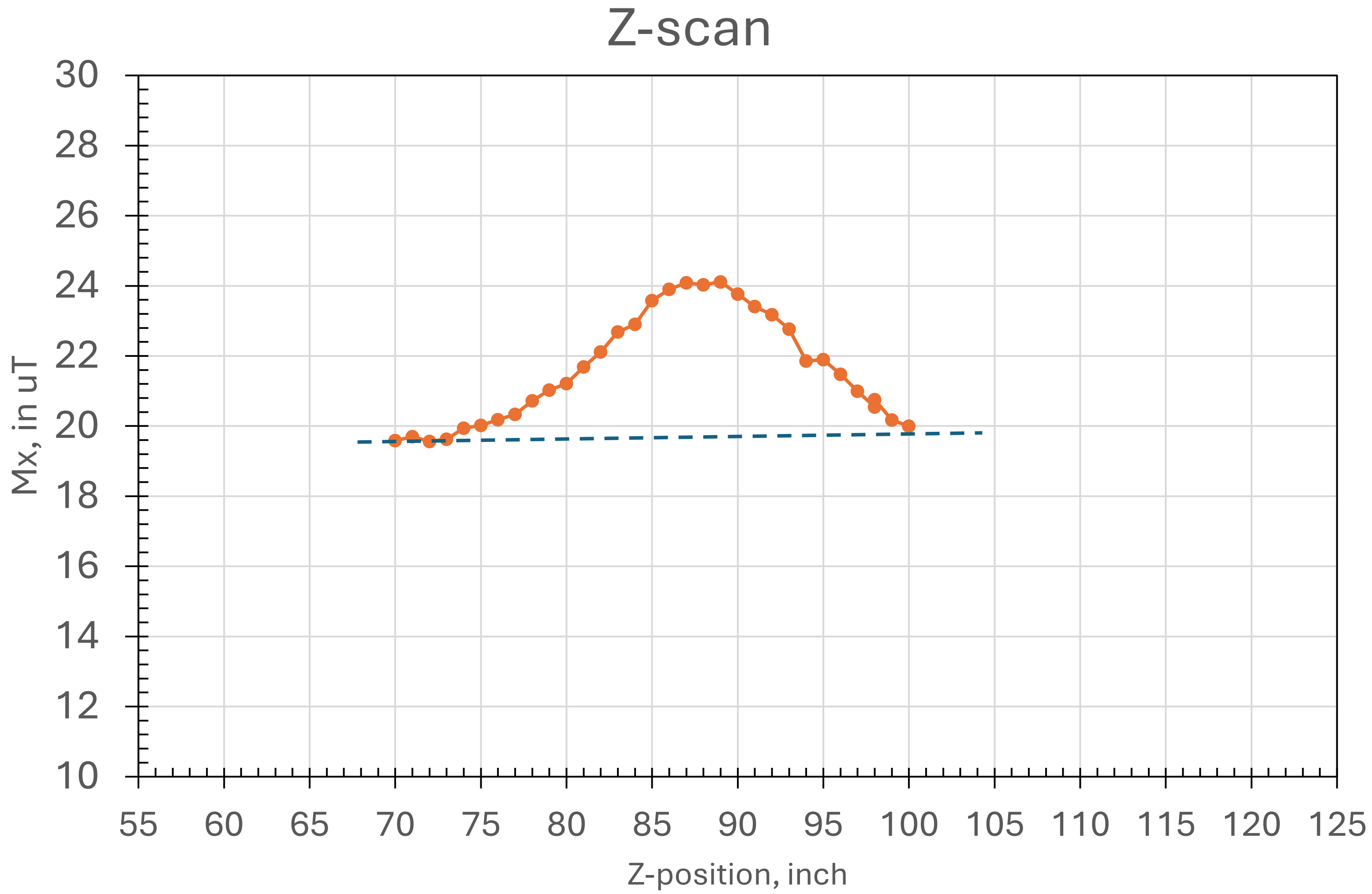

Single inner mu-layer
Seen PERT at 1.3 A
$\overline{\mathrm{PERT}}$= 16.1 $\pm$ 1.8 $\mu T$

DIFF dependence on current
~ 14.18 + 1.47$\cdot$ $i(A)$ $\mu T$

# 2 μ - inner layers

Double shielding is good. Difficult to see the perturbation peak after 2-$\mu$ shield

Special degaussing with 0A and NO PERT. Then, Z-scan with PERT, current 0 A




Peak position 88”

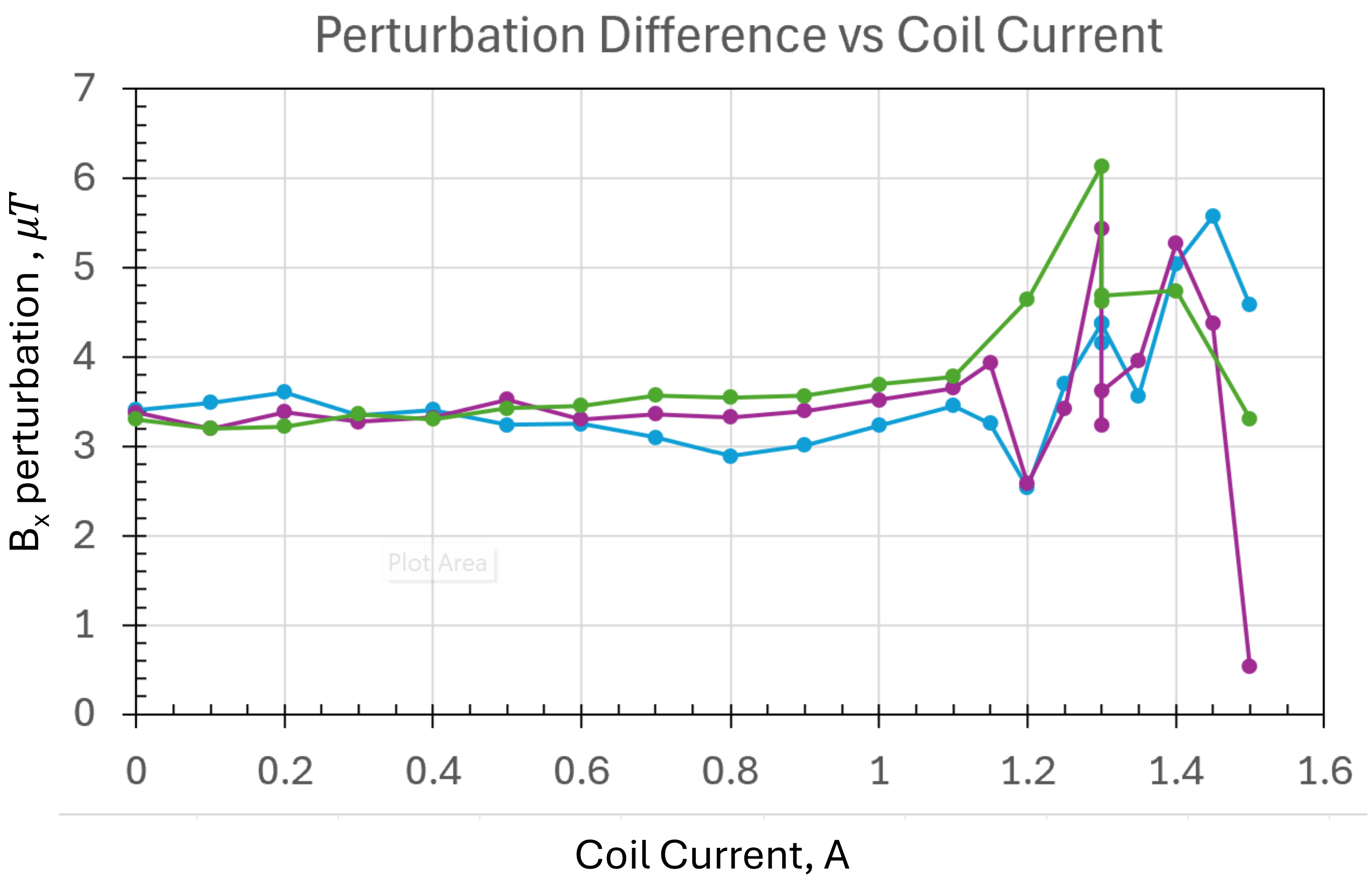
Perturbation ~ 4.5 $\mu T$

# 2 μ - inner layers

July 10-14, 29026

After Standard Degaussing, Z=88". DIFF=PERT-NOPERT, with Air

At smallest PERT signals (double layer) with large coil current temp. regime is not stable



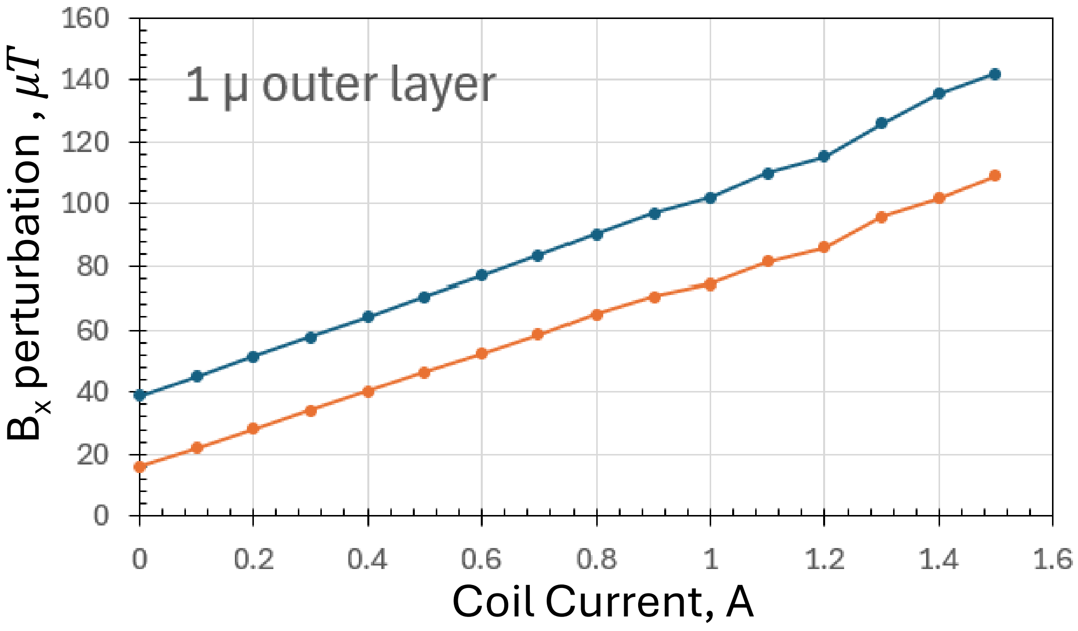

Double inner mu-layer
Seen PERT at 1.3 A
$\overline{\text{PERT}} = 4.51 \pm 0.61\ \mu T$

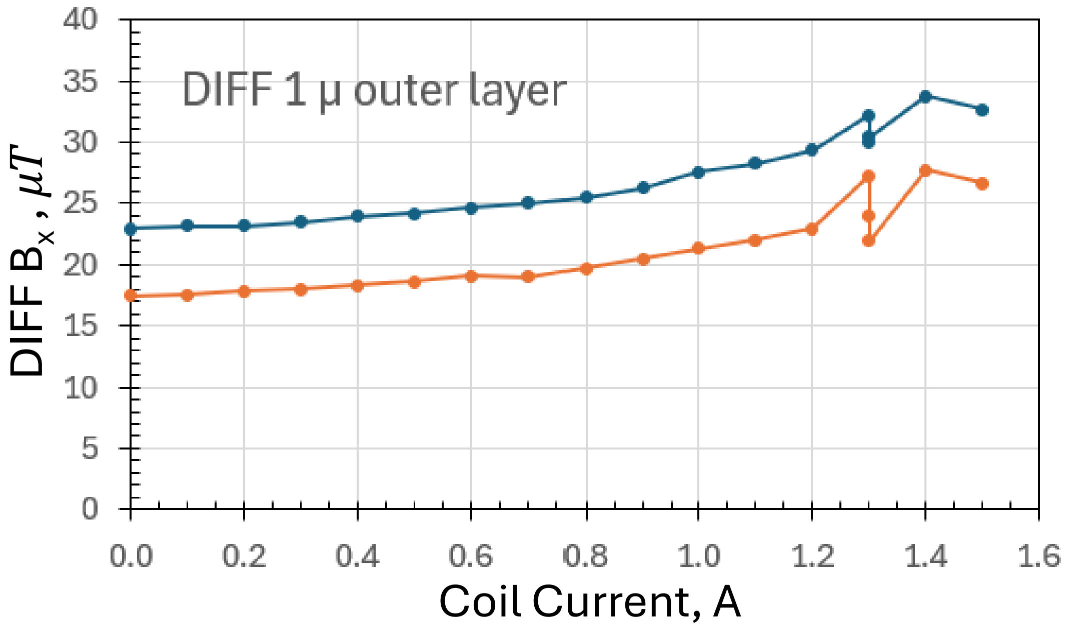
DIFF dependence on current
$\sim 1.2965 i^2 - 1.2367 i + 3.5084\ \ \mu T$

$$P = I^2 R$$

# 1 μ - OUTER layers

Standard degaussing, $B_x$ field with/without perturbation at z peak position 88”



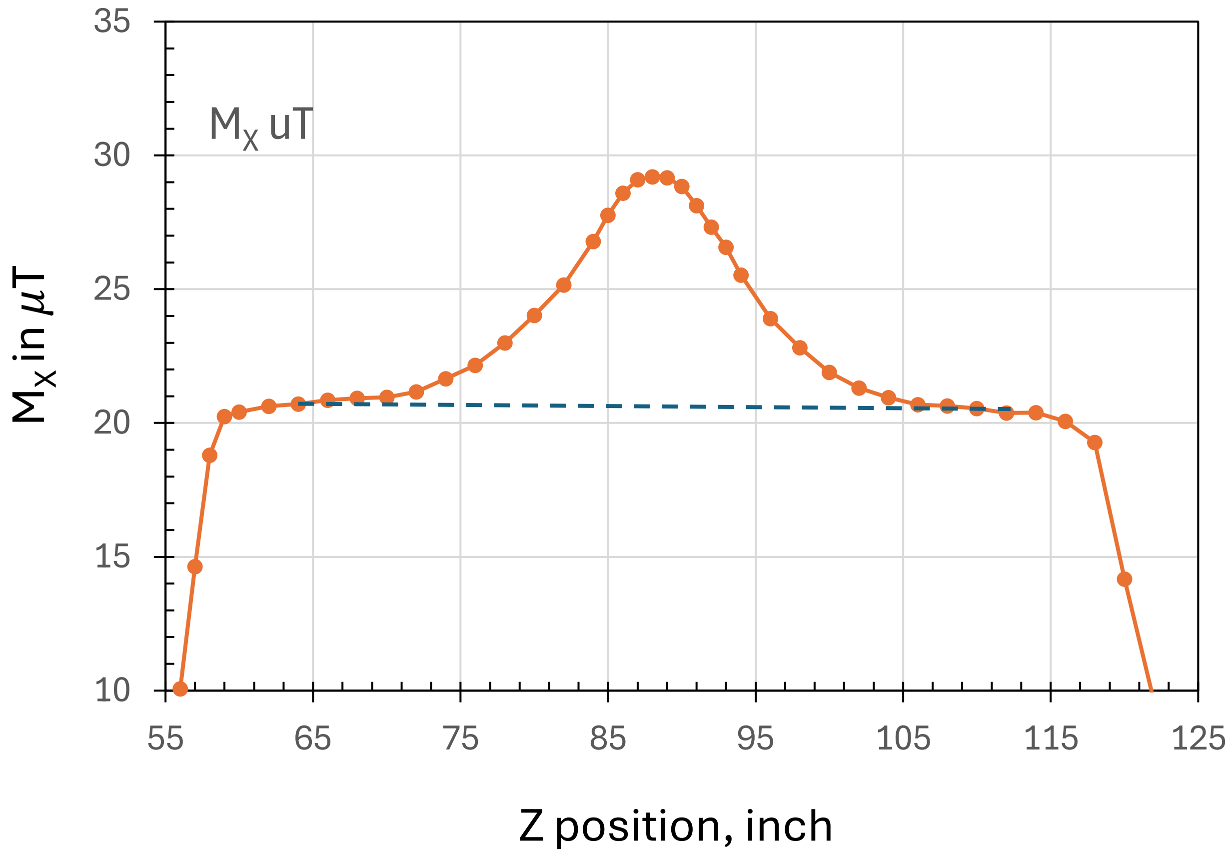




Single outer mu-layer seen PERT at 1.3 A
$\overline{\text{PERT}} = 27.6 \pm 3.7\ \mu T$

DIFF dependence on current
~ $5.27i^2 - 1.26i + 20.46\ \mu T$

# 2 μ - OUTER layers

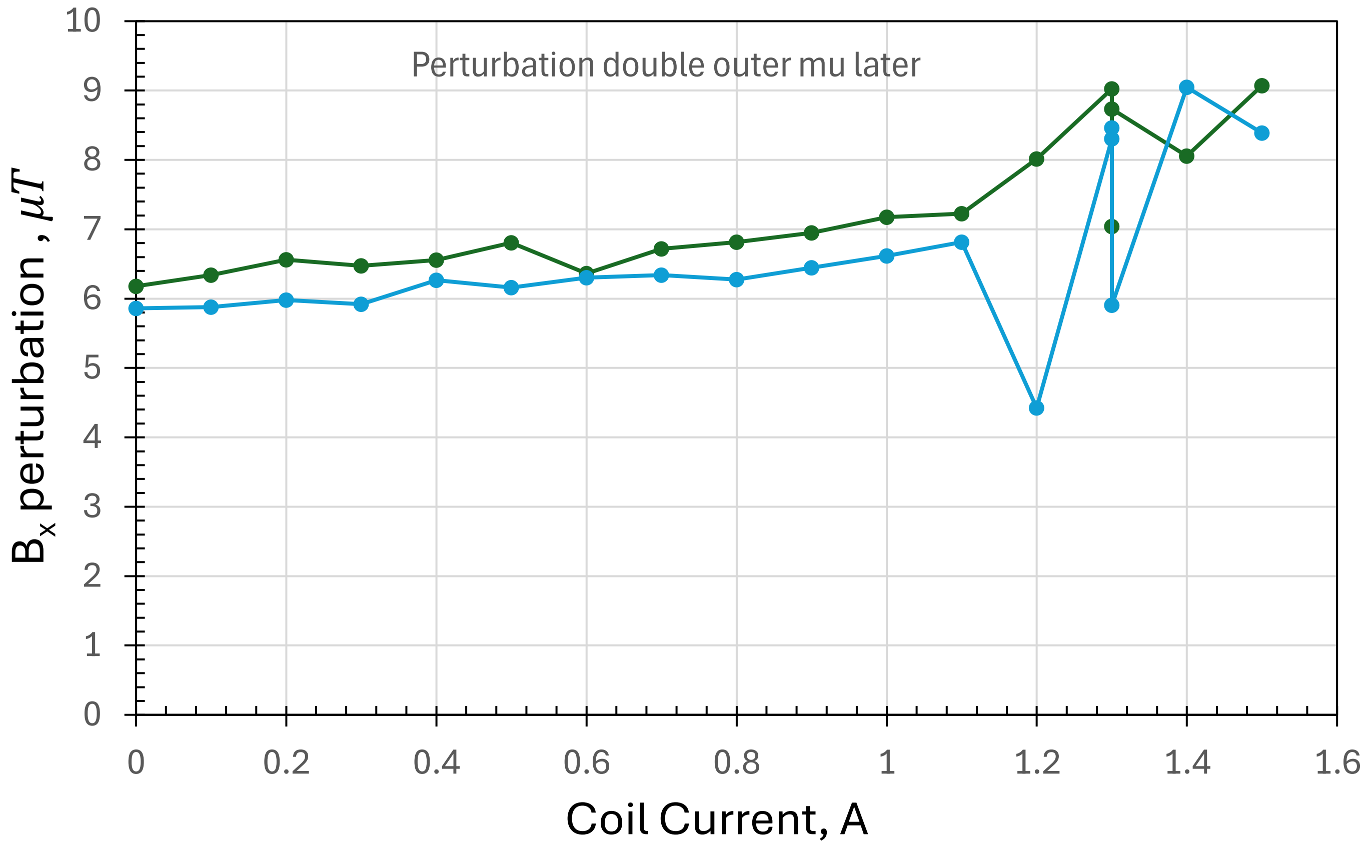
Special degaussing with 0A and NO PERT. Then, Z-scan with PERT, current 0 A




Peak position 88”
Perturbation ~ 8.6 $\mu T$

# 2 μ - OUTER layers

After Standard Degaussing, Z=88”. DIFF=PERT-NOPERT, with Air




Double outer mu-layer
Seen PERT at 1.3 A
$\overline{\mathrm{PERT}} = 7.9 \pm 1.1\ \mu T$

DIFF dependence on current
~ $1.713i^2 - 1.088i + 6.311\ \ \mu T$

# Summary of shielding factors

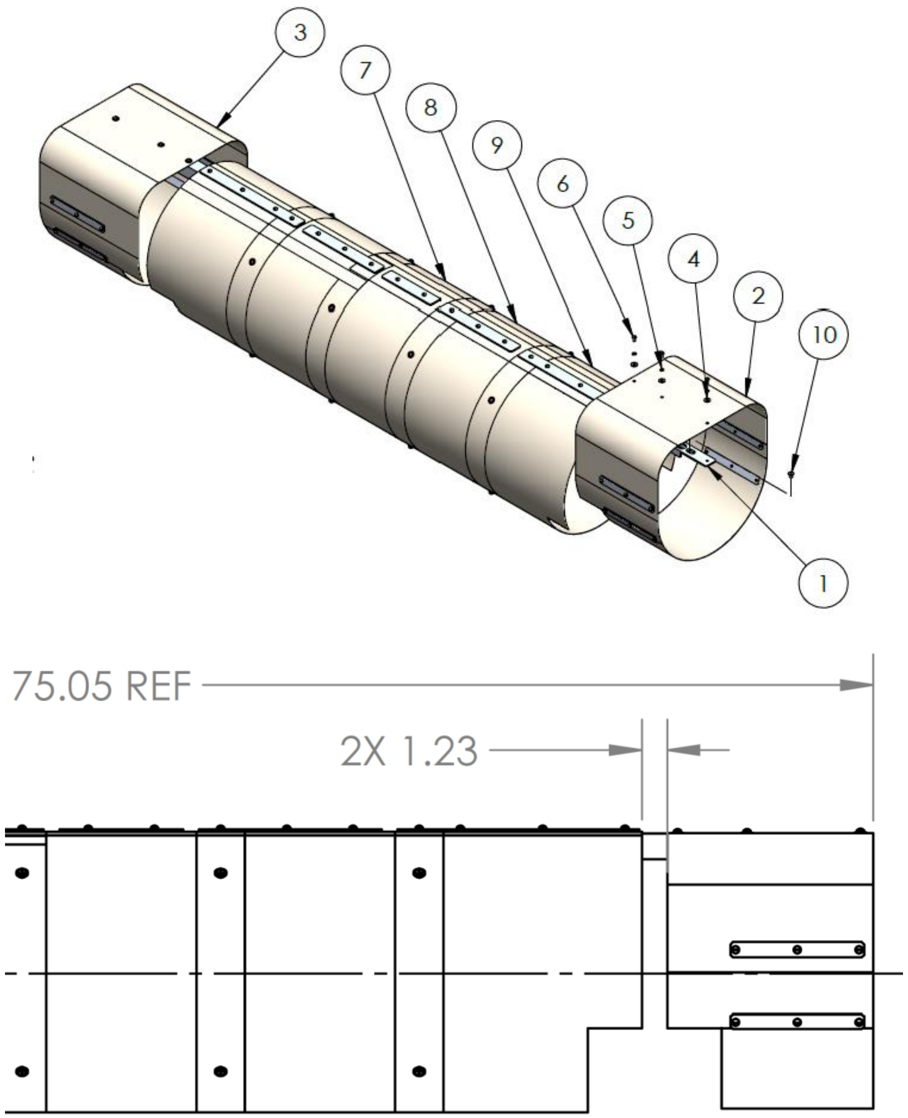
All measurements are after standard degaussing with coil current 1.3 A (~ 25 Gauss)

| Configuration | Diameter, inch | Seen PERT $\mu T$ | SF | $\mu_{eff}$ |
|---|---|---|---|---|
| 1$\mu$ inner layer | 7.5 (0.46mm) | 16.1$\pm$1.8 | 32.6$\pm$ 3.8 | 13,317 |
| 2$\mu$ inner layer | 7.6 (0.90mm) | $4.51 \pm 0.61$ | 116.2$\pm$16.1 | 24,050 |
| 1$\mu$ outer layer | 9.0 (0.38 mm) | $27.6 \pm 3.7$ | 19.0$\pm$2.6 | 11,220 |
| 2$\mu$ outer layer | 9.1(0.76 mm) | $7.9 \pm 1.1$ | 66.3$\pm$9.4 | 19,794 |

Effective thickness

- We did not have degaussing of the outer layer – maybe we should
- Double layer seems have higher $\mu$ probably due to effective space between two layers
- Layer thickness calculated effectively accounting for sheets overlay
- It was not possible measure SF with both inner and outer shields

## Gap in nTMM outer shield




## Gap simulated in prototype