NN' zoom meeting • March 24, 2026

Agenda:

1. Yuri - initial condition for density matrix evolution 10'
2. Linus & Nathan - Update on calculations for PRD paper 10'
3. Kyle - new simulations for fast neutrons at GP-SANS 10'
3. ~~Mubi - Update from UKY 10'~~
4. ~~Linus - Update from LU 10'~~
5. Yuri - Camera for reading pressure sensor 5'
6. Evan - μ Prototype Shielding Factor vs Coil Current 5'

What is correct as an initial condition of (n, n') system evolution: $\psi(0) = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ or average density matrix?

$$\hat{\rho} = \begin{pmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{pmatrix} \qquad \rho_{12} = \rho_{21}^*$$

$$\left\{ \begin{array}{ll} \rho_{11} = \psi_n \psi_n^* = P_n(t) & \rho_{12} = \psi_n \psi_{n'}^* \\ \rho_{21} = \psi_{n'} \psi_n^* & \rho_{22} = \psi_{n'} \psi_{n'}^* = P_{n'}(t) \end{array} \right\}$$

Trivial initial state of $\psi \equiv \begin{pmatrix} \psi_n \\ \psi_{n'} \end{pmatrix} = \begin{pmatrix} n \\ n' \end{pmatrix}$ system is $\psi(0) = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$

and corresponding density matrix $\hat{\rho}(0) = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$.

This initial state is realized when neutron is released from nuclei or neutron is reflected from the guide walls.

At all times after starting from $\begin{pmatrix}1\\0\end{pmatrix}$ state neutron is oscillating .

With the $\Delta m \neq 0$ MM model in vacuum (no magnetic field)

$$\tan 2\theta_0 = \frac{2\epsilon}{\Delta m} \qquad E_{1,2} = \frac{\Delta m}{2} \pm \sqrt{\left(\frac{\Delta m}{2}\right)^2 + \epsilon^2} = \frac{\Delta m}{2} \pm \omega$$

$$\omega^2 = \left(\frac{\Delta U}{2}\right)^2 + \epsilon^2$$

$$\cos\theta_0 \equiv \mathrm{c}; sin\,\theta_0 \equiv \mathrm{s}$$

$$\exp\{-iE_1 t\} \equiv e_1$$

$$\exp\{-iE_2 t\} \equiv e_2$$

$$n_1 = \mathrm{c} \cdot \exp\{-iE_1 t\} \equiv ce_1$$

$$n_2 = s \cdot \exp\{-iE_2 t\} \equiv se_2$$

- eigenstates = plane wave solutions for energy eigenstates

$$n = cn_1 + sn_2 = c^2\, e_1 + s^2\, e_2 \qquad \exp\{-iE_1 t\} \equiv e_1$$

$$n' = -sn_1 + cn_2 = sc(-e_1 + e_2) \qquad \exp\{-iE_2 t\} \equiv e_2$$

$$P_{n'}(t) = n'^*\, n' = (cs)^2(e_1^* e_1 + e_2^* e_2 - e_1 e_2^* - e_2 e_1^*)$$

$$e_1^* e_1 = \exp\{+iE_1 t\} \cdot \exp\{-iE_1 t\} = 1 \quad ; \quad (E_1 - E_2) = \Delta E = 2\omega$$

$$e_1 e_2^* = \exp\{-iE_1 t\} \cdot \exp\{+iE_2 t\} = \exp\{-i\Delta E \cdot t\}$$

$$e_2 e_1^* = \exp\{-iE_2 t\} \cdot \exp\{+iE_1 t\} = \exp\{+i\Delta E \cdot t\}$$

$$P_{n'}(t) = (cs)^2\left[2 - \underbrace{\left(e^{+i2\omega t} + e^{-i2\omega t}\right)}_{2\cos 2\omega t}\right] = \underbrace{4c^2 s^2}_{sin^2\, 2\theta_0} sin^2 \omega t$$

$$P_{n'}(t) = sin^2 2\theta_0 \cdot sin^2 \omega t \qquad P_n(t) = 1 - sin^2 2\theta_0 \cdot sin^2 \omega t$$

$$P_{n'}(t) = \rho_{22} = sin^2 2\theta_0 \cdot sin^2 \omega t$$

$$P_n(t) = \rho_{11} = 1 - sin^2 2\theta_0 \cdot sin^2 \omega t$$

$$\rho_{12}(t) = \psi_n \psi^*_{n'} = (c^2\, e_1 + s^2\, e_2) \cdot sc(-e_1 + e_2) =$$

$$= -\frac{1}{2} sin4\theta_0 \cdot sin^2 \omega t - \frac{i}{2} sin2\theta_0 \cdot sin2\omega t \quad ;$$

(#)

$$\rho_{21} = \rho^*_{12}$$

These eqs. define $\hat{\rho}\,(t)$ as function of time from initial state $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$.

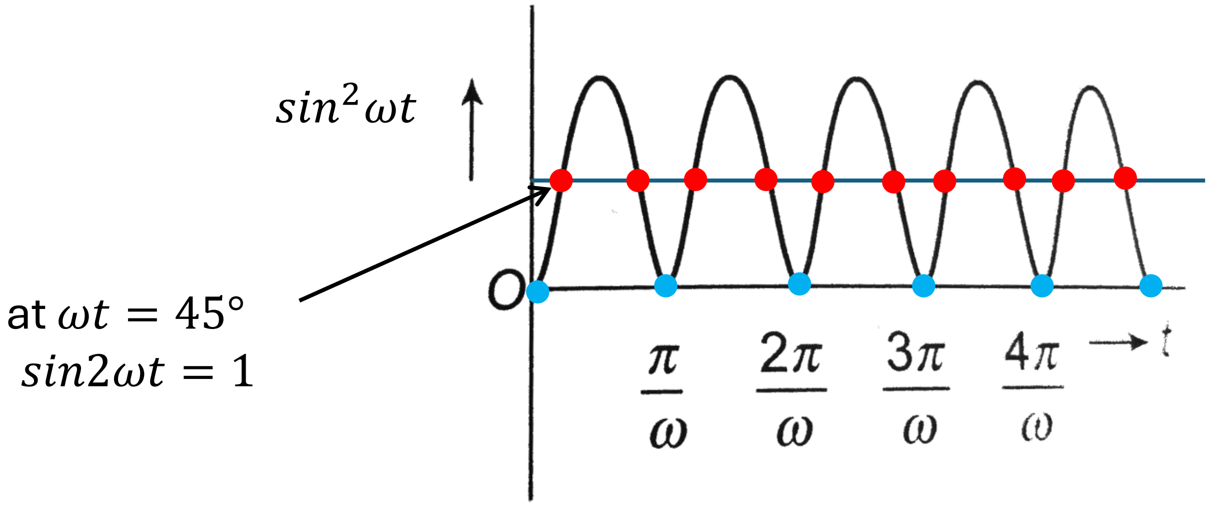
Since time average $\overline{sin^2 \omega t} = \frac{1}{2}$ and $\overline{sin2\omega t} = 0$ we can define average $\bar{\rho}$

$$\bar{\rho} = \begin{pmatrix} 1 - \frac{1}{2} sin^2 2\theta_0 & -\frac{1}{4} sin\, 4\theta_0 \\ -\frac{1}{4} sin\, 4\theta_0 & \frac{1}{2} sin^2 2\theta_0 \end{pmatrix}$$

After averaging the imaginary part expectantly disappears

$$\bar{\rho} = \begin{pmatrix} 1-\frac{1}{2}sin^2 2\theta_0 & -\frac{1}{4}\sin 4\theta_0 \\ -\frac{1}{4}\sin 4\theta_0 & \frac{1}{2}sin^2 2\theta_0 \end{pmatrix}$$ for small θ_0 $\bar{\rho} = \begin{pmatrix} 1-2\theta_0^2 & -\theta_0 \\ -\theta_0 & 2\theta_0^2 \end{pmatrix}$

- Is it possible to use $\bar{\rho}$ as an initial state of evolution?
- The answer would be YES if $\bar{\rho}$ at some time t^* would represent the real evolution state described by non-averaged density matrix $\hat{\rho}(t)$
- For this to happen in (#) conditions $sin^2\omega t = \frac{1}{2}$ and $sin2\omega t = 0$ should occur at the same time t^*. That is impossible!



- On another side, condition when $sin\omega t = 0$ is repeated periodically resulting in density matrix state $\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$ or $\psi = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$

Conclusion: state $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ should be used as initial condition in vacuum

- if the frequency ω is big enough. [for our lowest $\Delta m = 6 \times 10^{-11} eV$
  $\omega > 4.5 \times 10^{+4}$, or $T = 2\pi/\omega = 138\ \mu s$
  or the length of period $L = 13.8\ cm$ for velocity 1000 m/s
- velocity averaging should be used
- $\bar{\rho}$ is only good for showing the average state of the system.

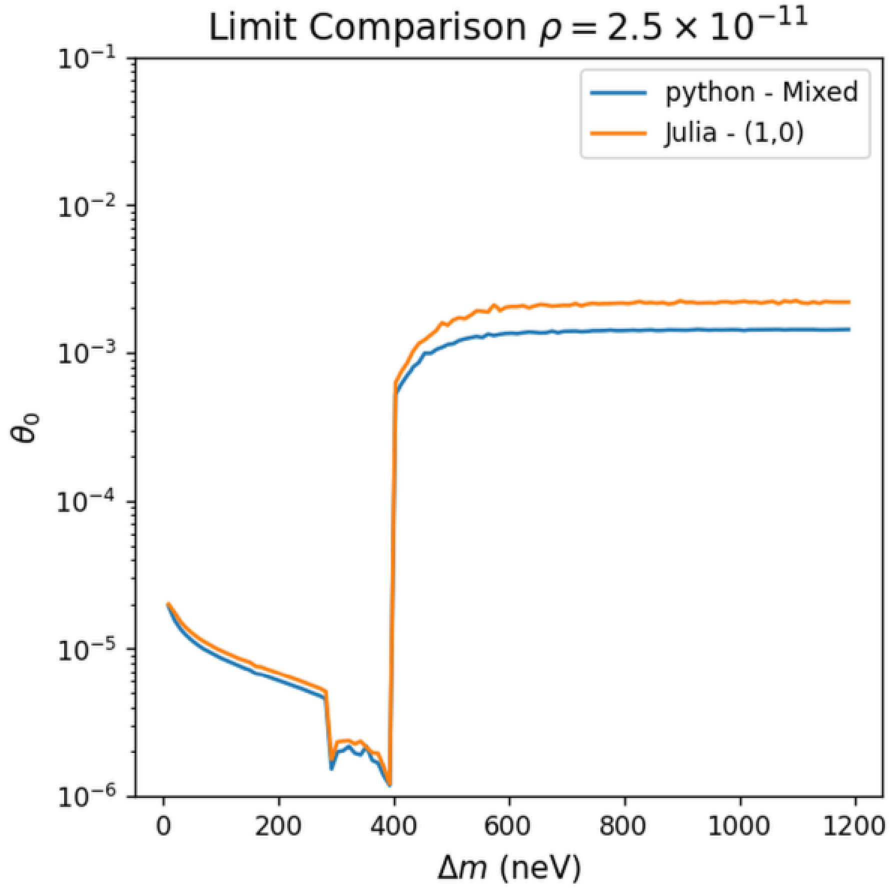
Correction to fractional residuals

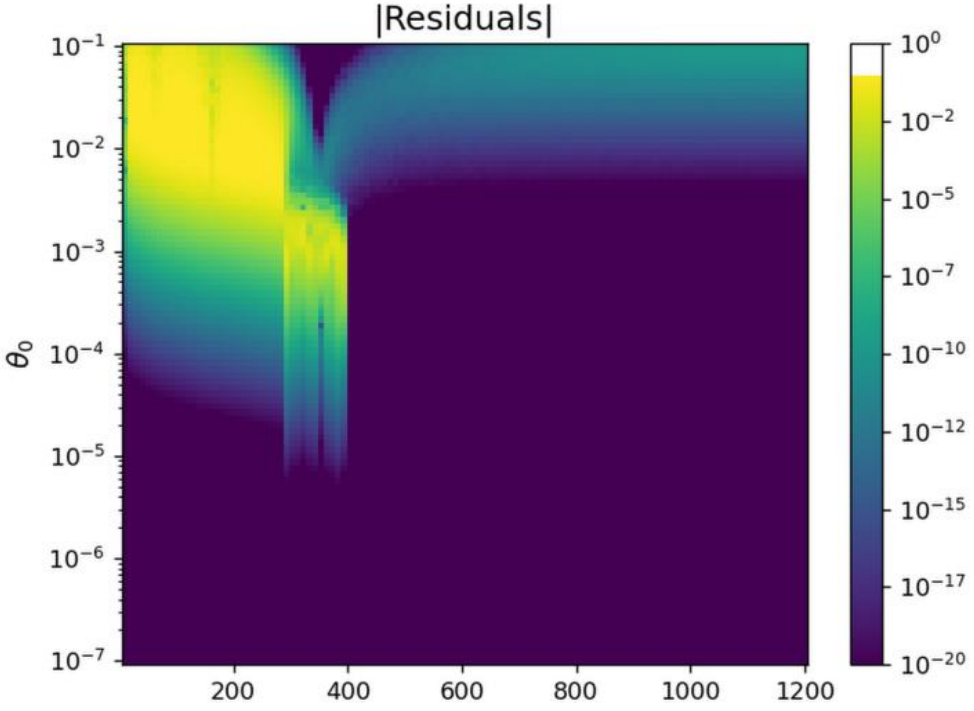
- All Fractional residuals shown have been in **log** scale
- $(\rho_2 - \rho_1)/\rho_2 * 100$

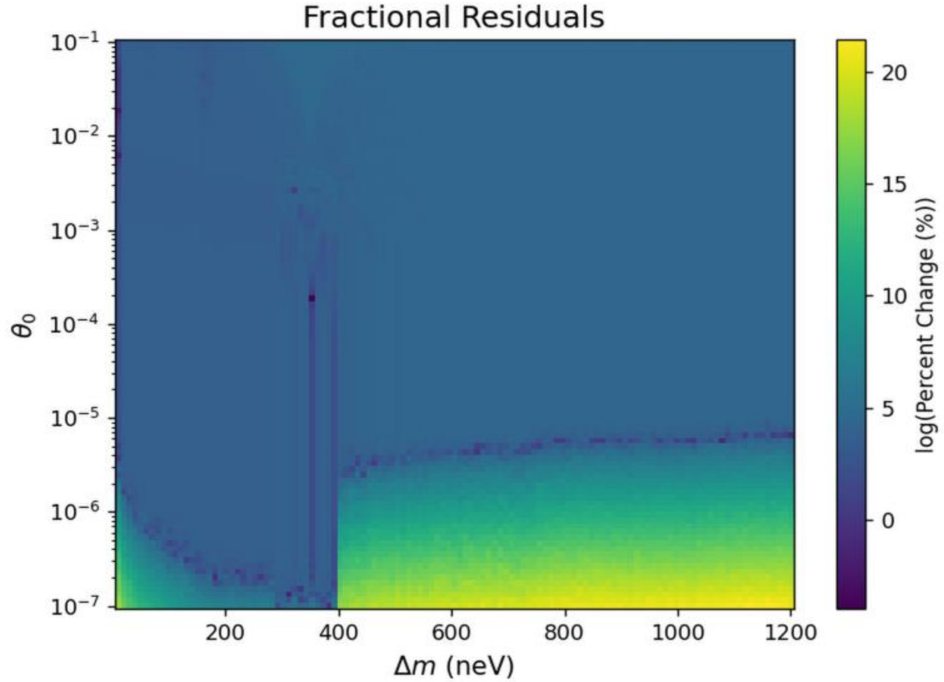
Mixed State vs Pure State

- Pure initial state: $\Psi i = (1, 0)^T$
- Time averaged mixed state: $\Psi i = (2\theta^2, 1\text{-}2\theta^2,)^T$

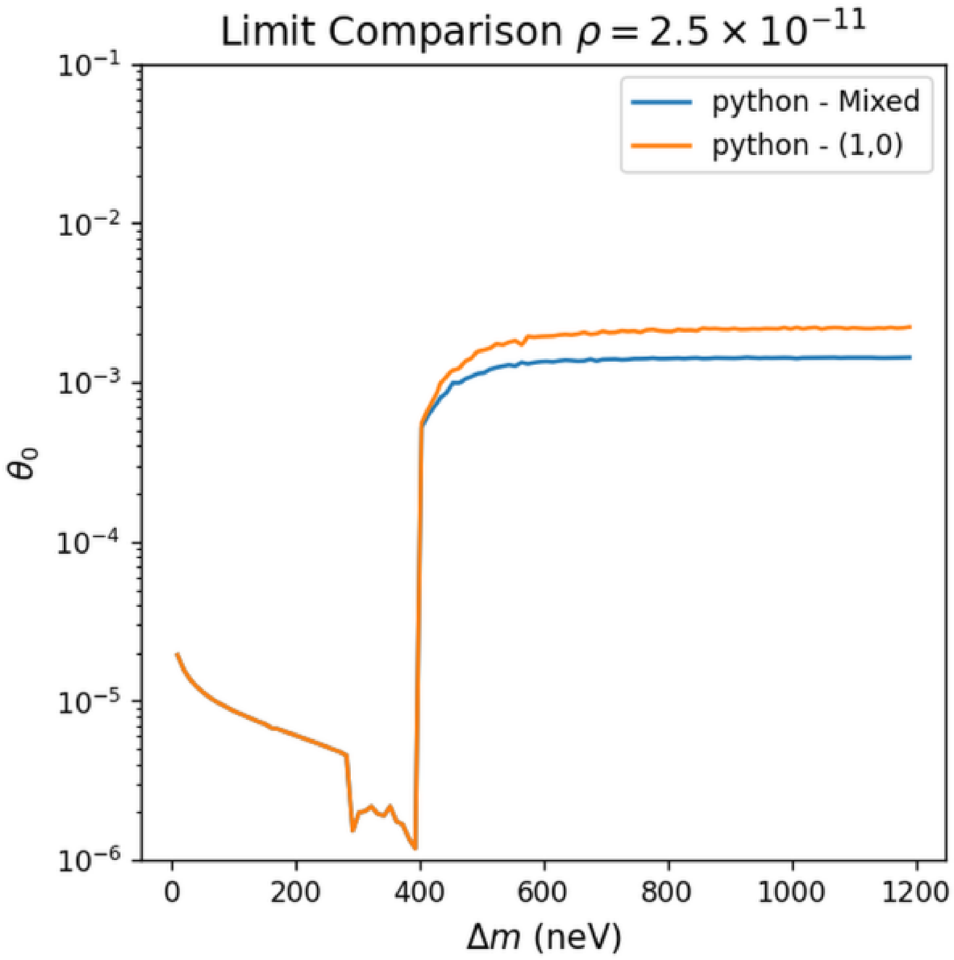
Python (mixed) vs Julia

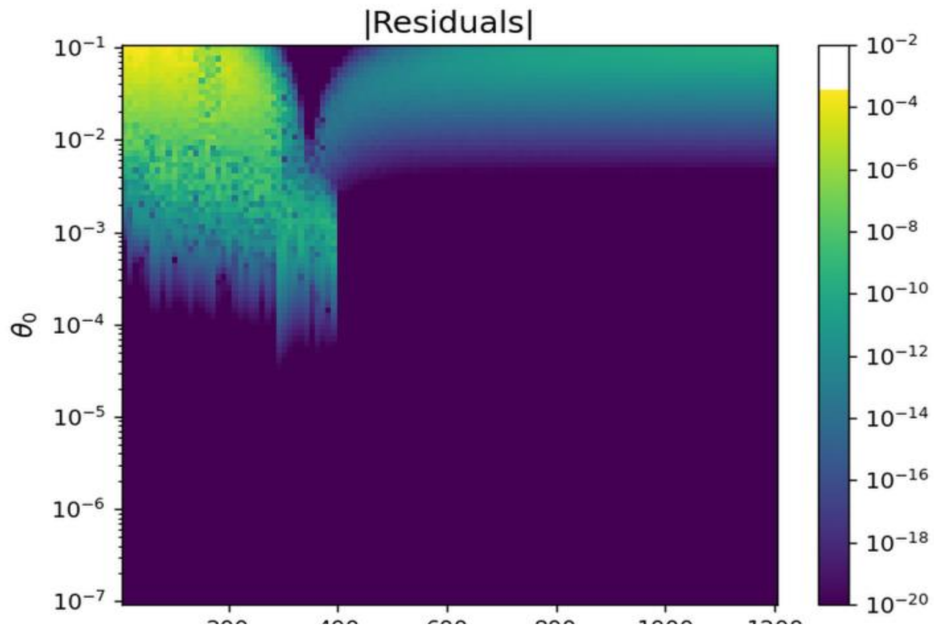


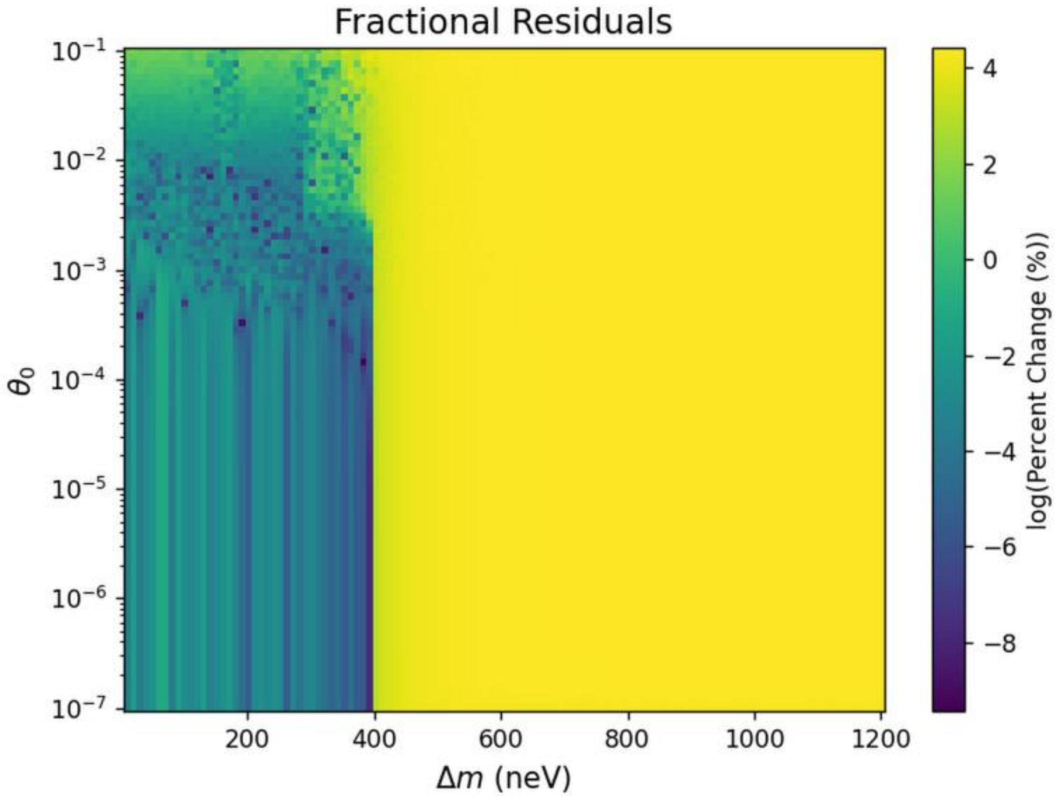




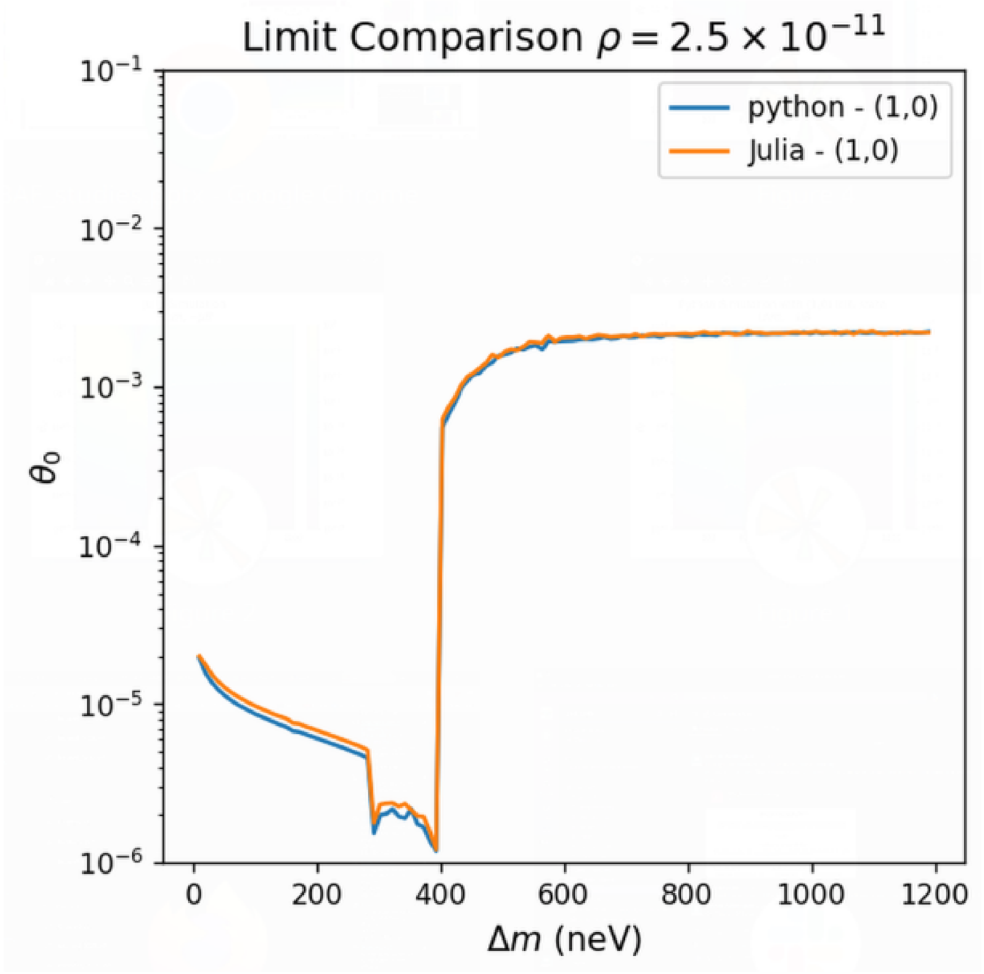
Python (mixed) vs Python (1,0)

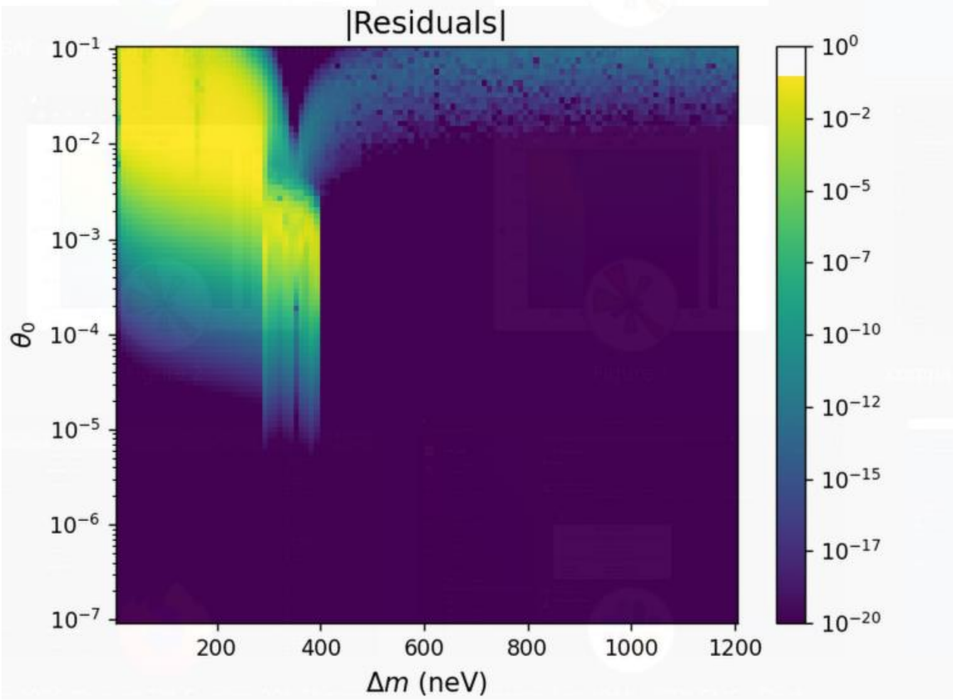


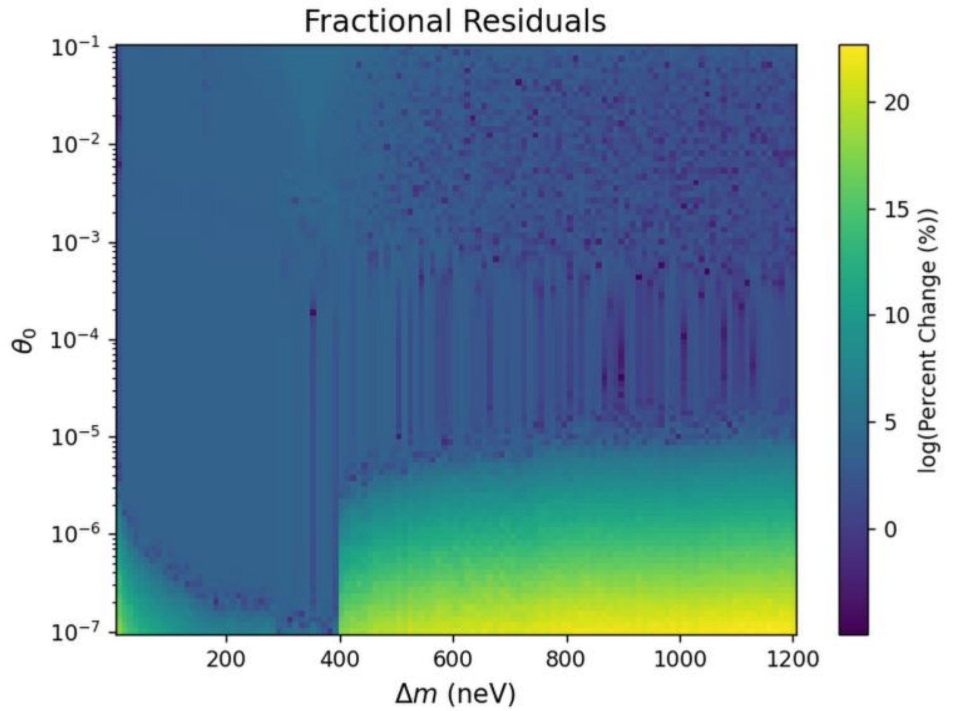




Python (mixed) vs Julia (1,0)







https://www.amazon.com/dp/B0FXXFP497?ref=ppx_yo2ov_dt_b_fed_asin_title

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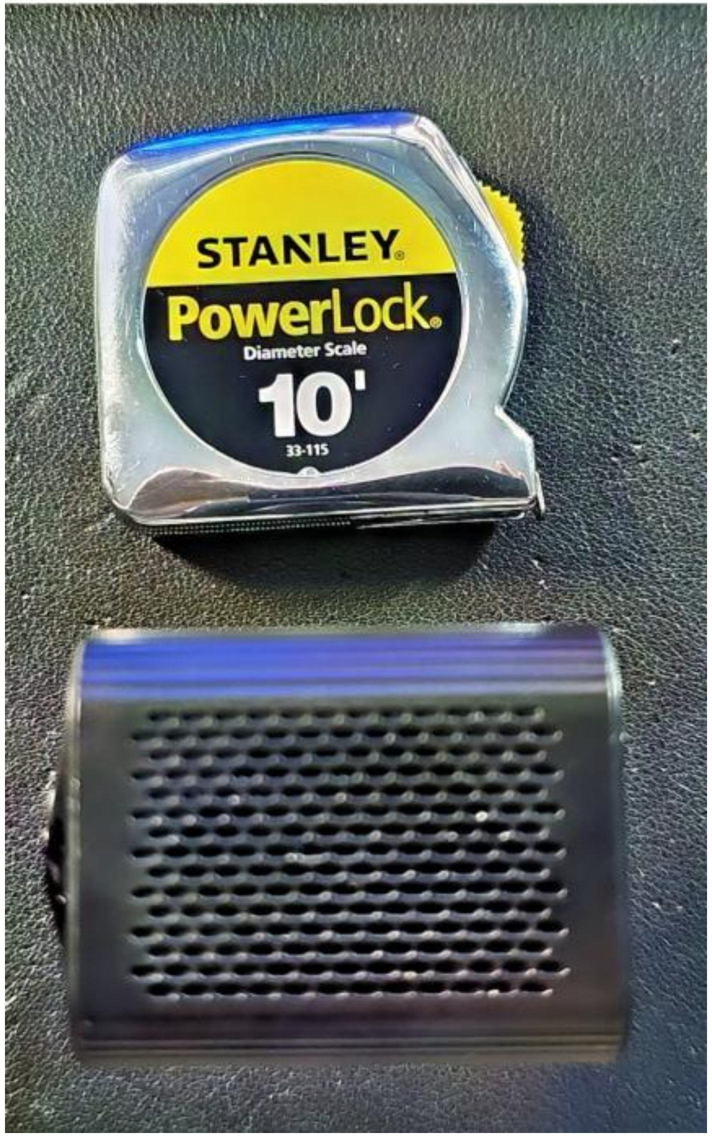
Mini Video HD Camera for Pressure readout

1.93 x 1.5 x 0.67 inches


STANLEY
PowerLock
Diameter Scale
10'
33-115


STANLEY
PowerLock
Diameter Scale
10'

Image from the phone

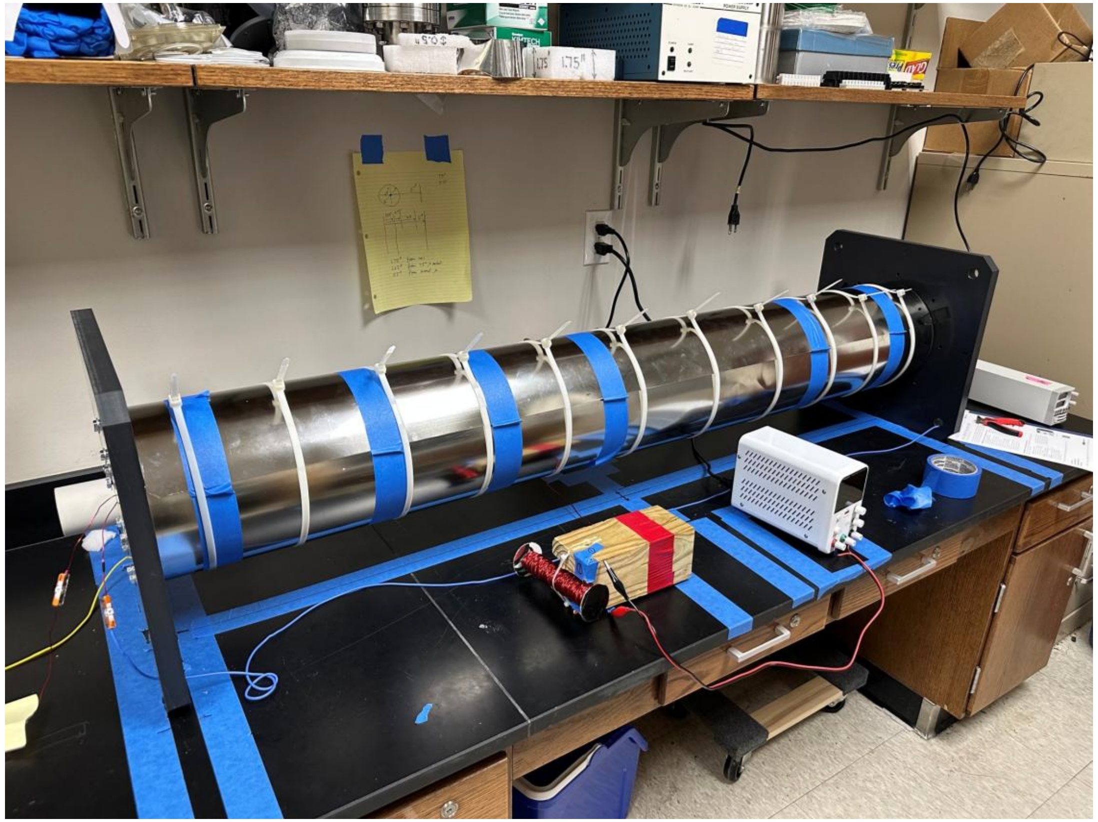
Camera at the distance 24”

Prototype Shielding Factor Dependence on Coil Current

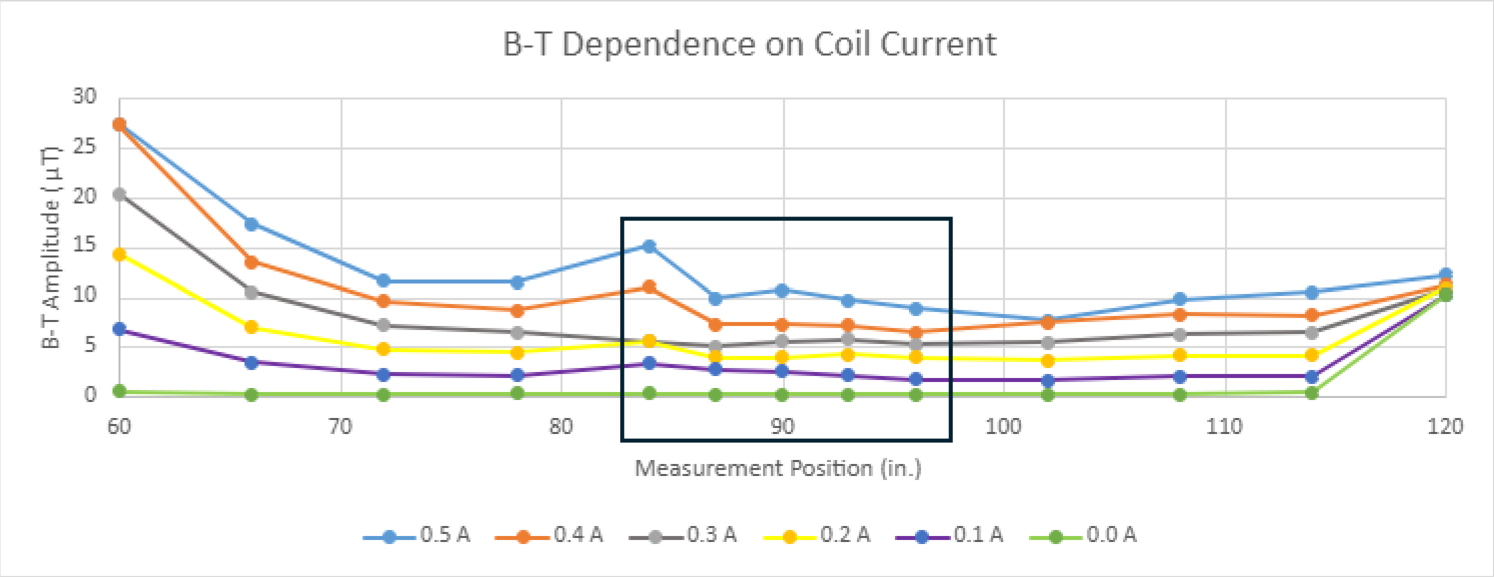
Evan Michael UTK 3/24/2026

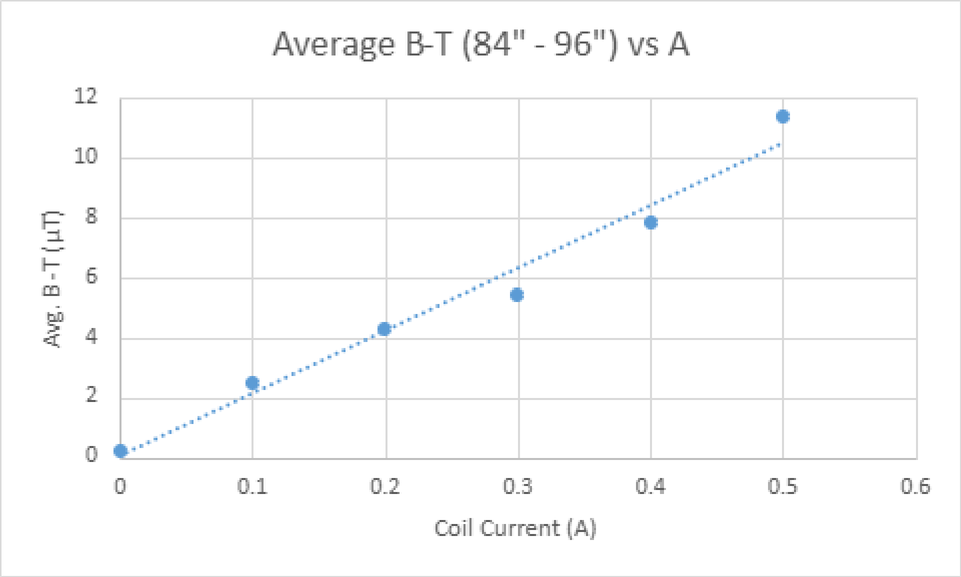
MuMETAL Permeability

- The cylindrical MuMETAL shielding around the solenoids acts a magnetic field flux return path due to higher permeability than air
- MuMETAL permeability changes with applied magnetic field according to B-H curve.
- Absorption and redirection of magnetic field flux from solenoid should be studied to understand effect on shielding factor (SF)
- Adjusted prototype current strength between scans to evaluate. Single degaussing before testing (keeping initial magnetization state).



Transversal Magnetic Field Comparisons (0.5 to 0.0 A)

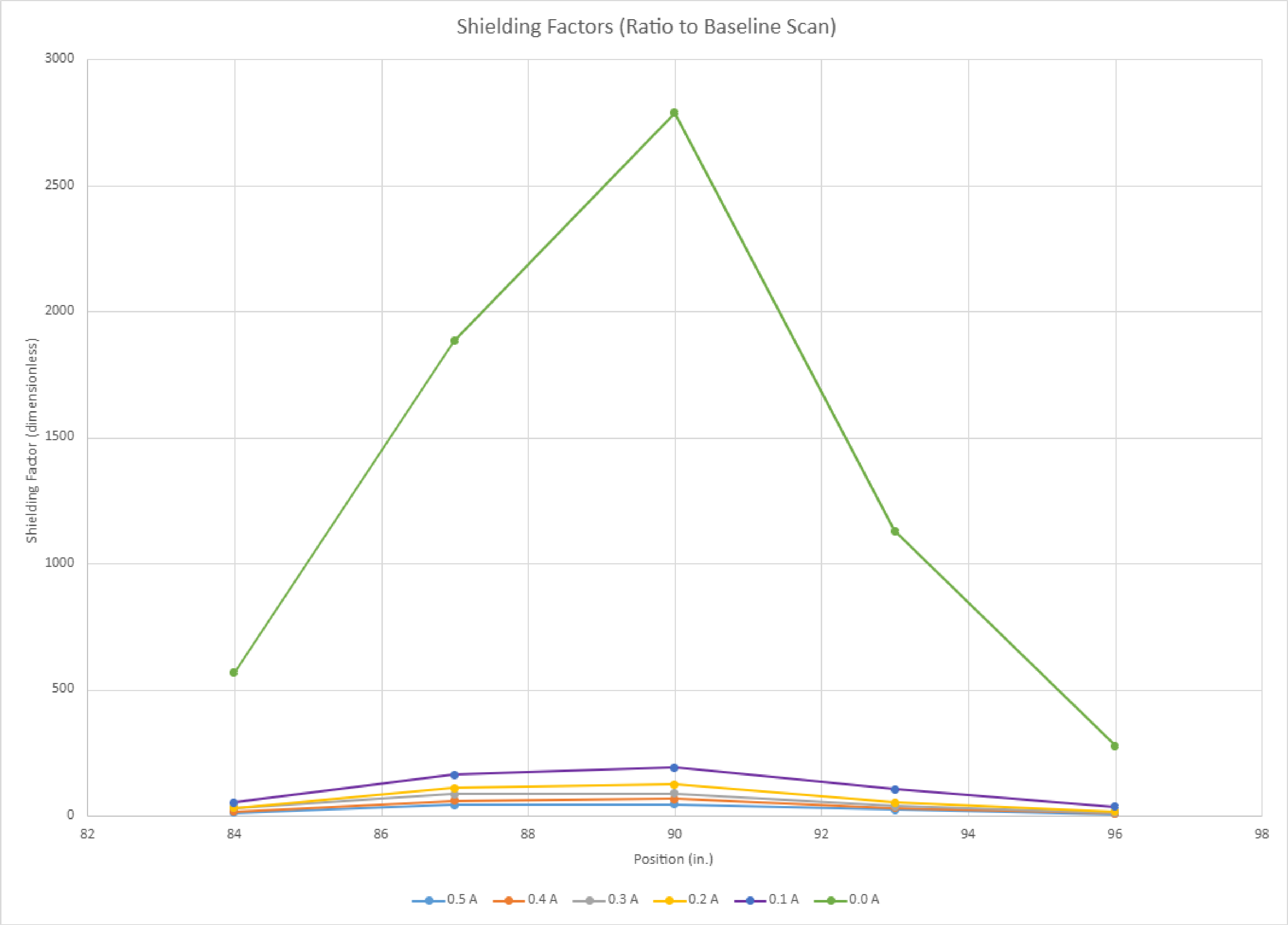




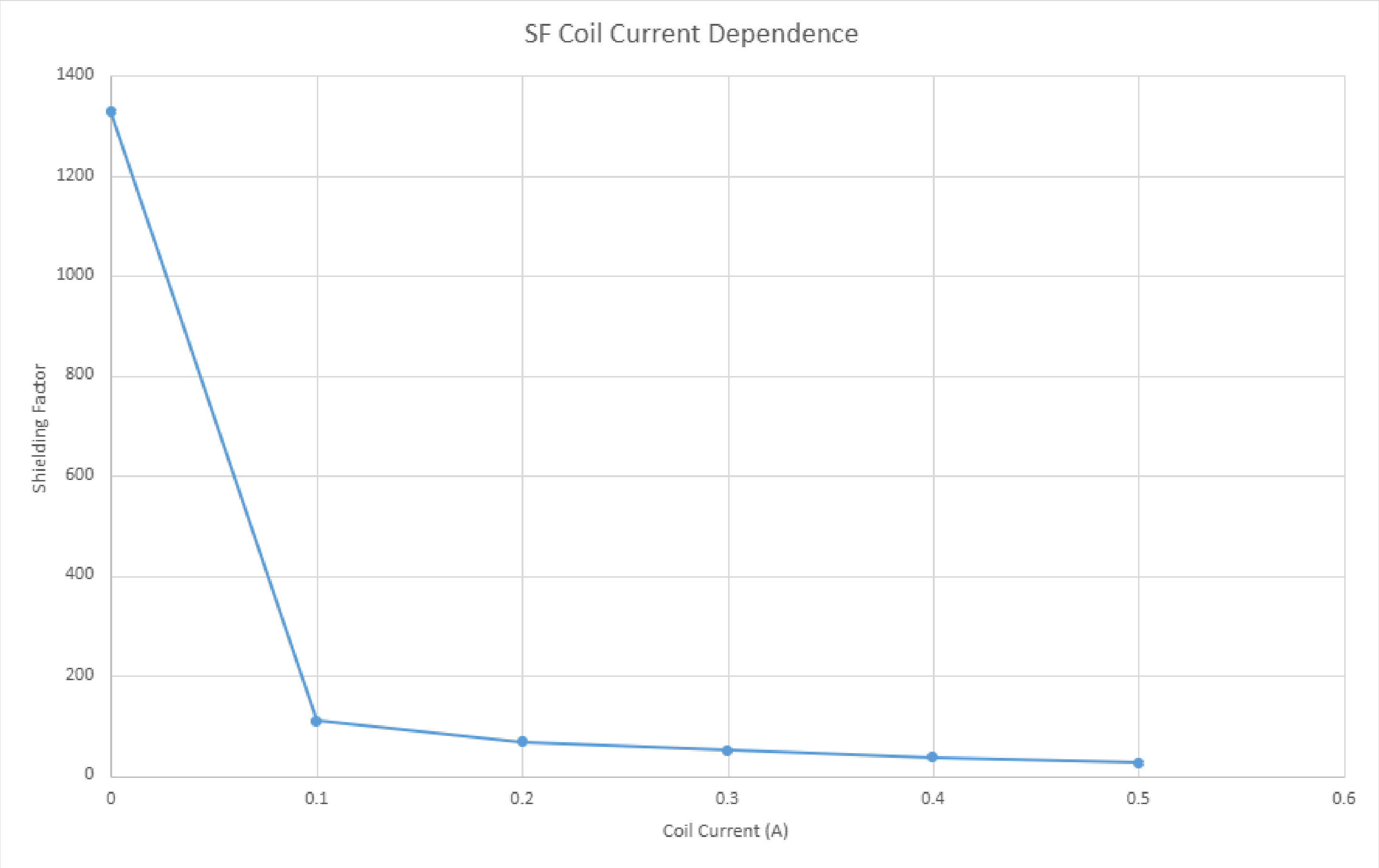
- Max ΔµT (Average B-Transversal from 84” to 96”): 11.2 µT
- Approximately linear relationship between applied current and B-T

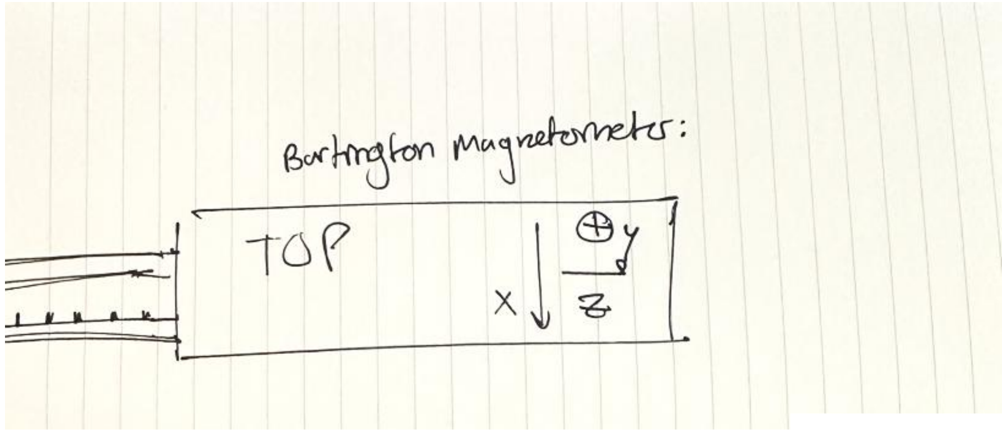
Shielding Factor Comparisons (0.5 to 0.0 A)

- Compared to a background of no shielding, 0.5 A coil current, approx. 5 G perturbation
- Solenoid produces approx. 10 G solenoidal field, but MuMETAL quoted to not saturate until 7000-8000 G
- Why such low SF at current application?
- Variation in SF maybe due to lateral magnetometer movement
- Repeat needed

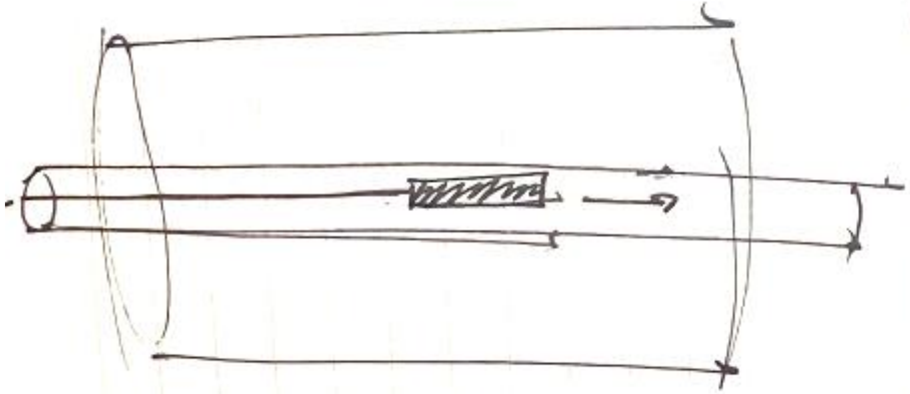


Additional Comparison

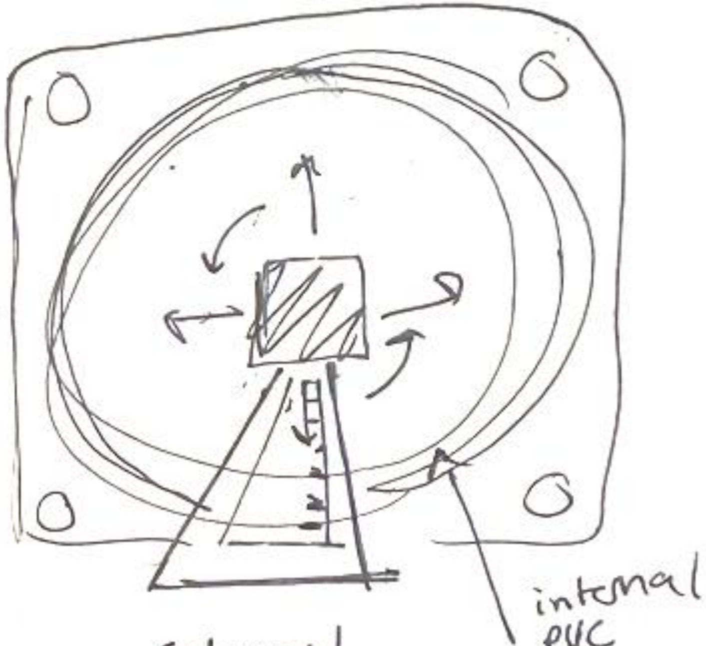




solenoid
(side view)



- Lateral movement of magnetometer may catch z-axis B-field along xy-plane



Solenoid
(front view)