# Compensation of Magnetic Fields in the TRIUMF nEDM Experiment

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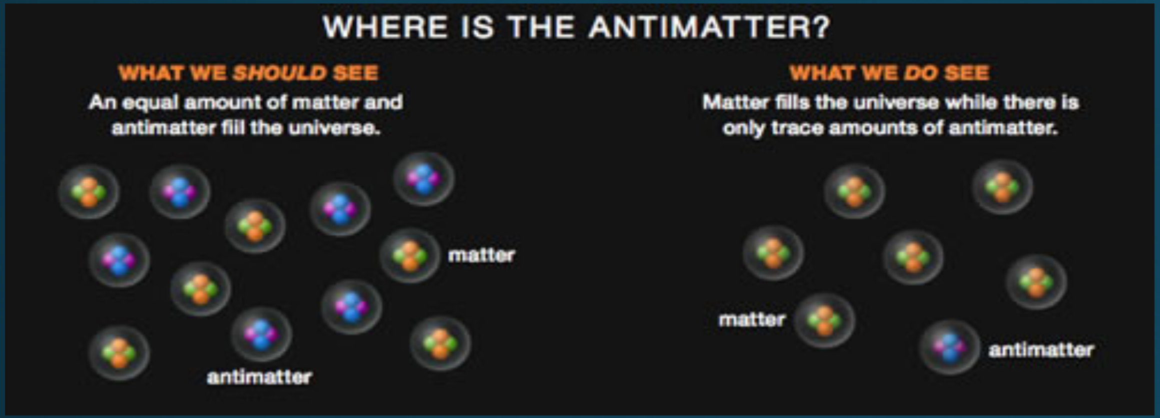
# Motivation Behind nEDM Experiment



From https://todaysnews2.blogspot.ca/2015/09/matter-and-antimatter-are-mirror-images.html

Sakharov Conditions (1967) for Baryogenesis

- Baryon number violation
- C and CP violation
- Departure from thermodynamic equilibrium

Andrei Sakharov

Experimentally[1] , $\eta = \frac{\eta_B - \eta_{B'}}{\gamma} = 6 * 10^{-10} \, \frac{excess\ baryons}{photon}$

Standard Model fails to explain. Reason : Not enough CP violation.

Requires

- Additional CP violation near TeV scale

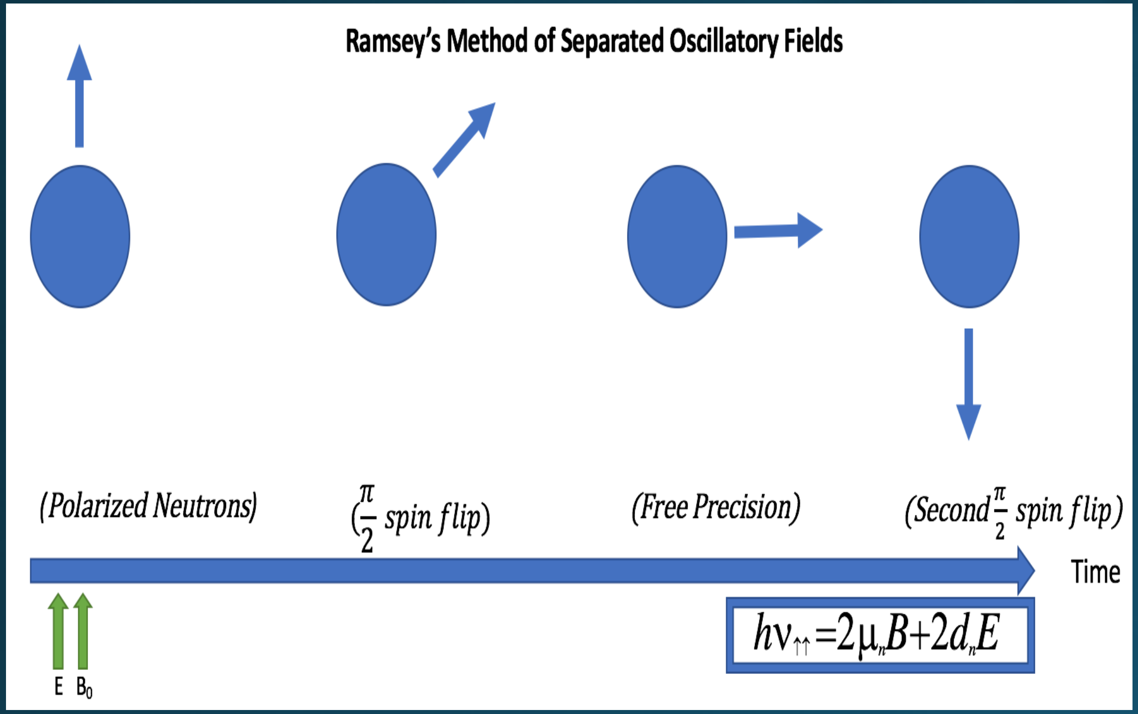
In turn ,

- Generating a nEDM to be $10^{-26}$ - $10^{-28}$ e-cm .

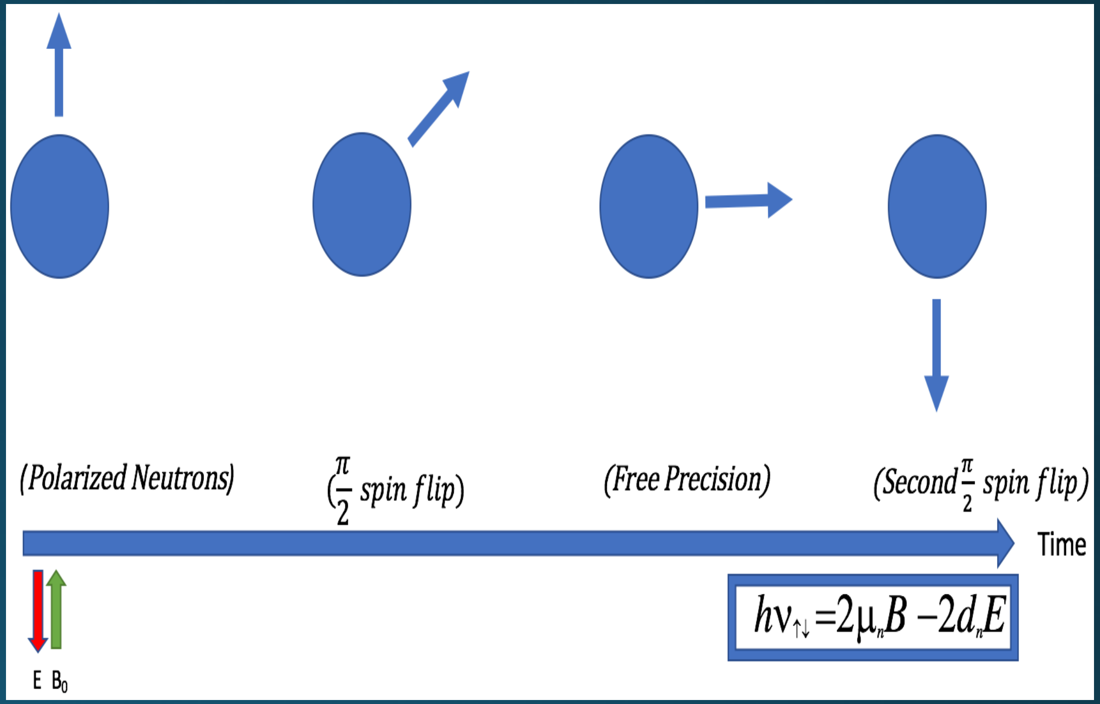
- The current best upper limit[2] set by Sussex/RAL/ILL nEDM experiment is $3.0 \times 10^{-26}$ e-cm.
- The nEDM experiment at TRIUMF is aiming at the $10^{-27}$ e-cm level in Phase 2 operations.

1. V.Barger et al. Phys.Lett. B 566 , 8(2003).
2. J. M. Pendlebury et al.Phys. Rev. D 92, 092003(2015).

# How To Measure nEDM?



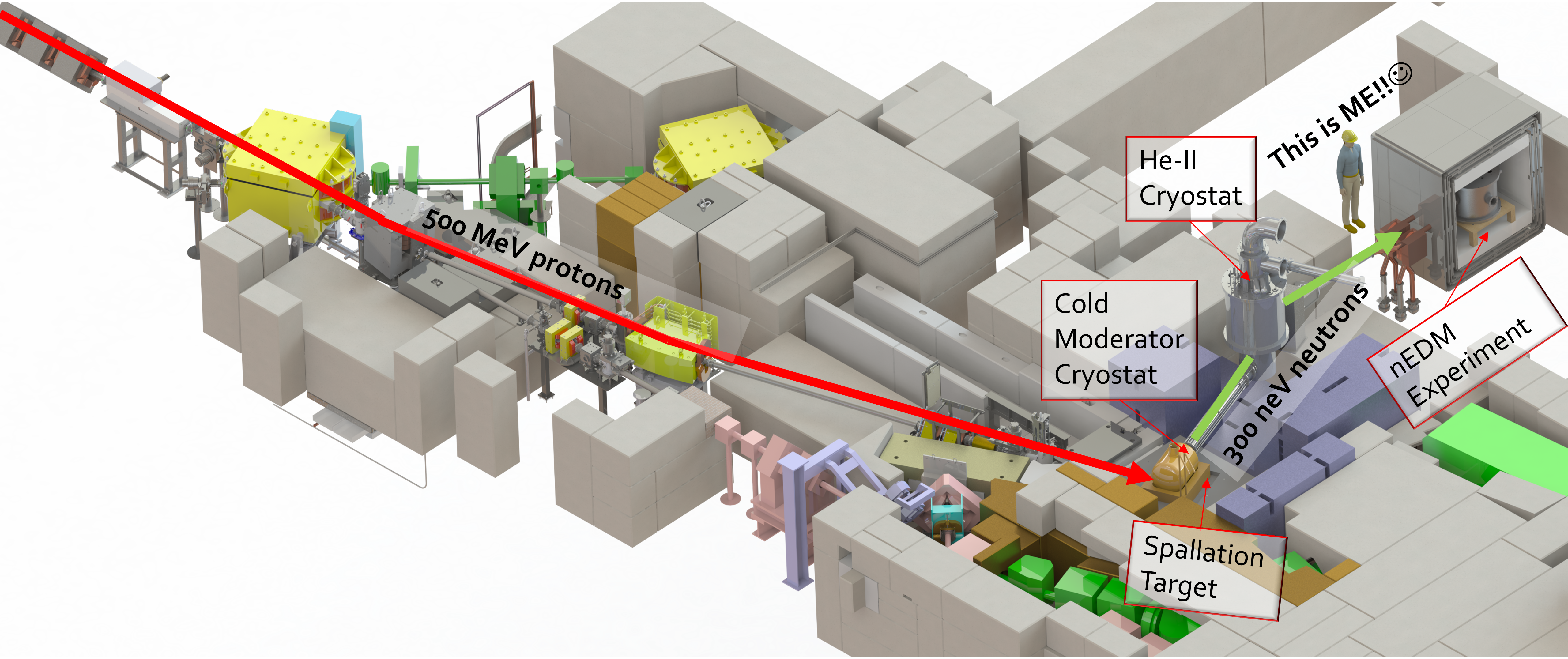
Repeat



**Now, if the magnetic field is very stable and homogeneous ,**

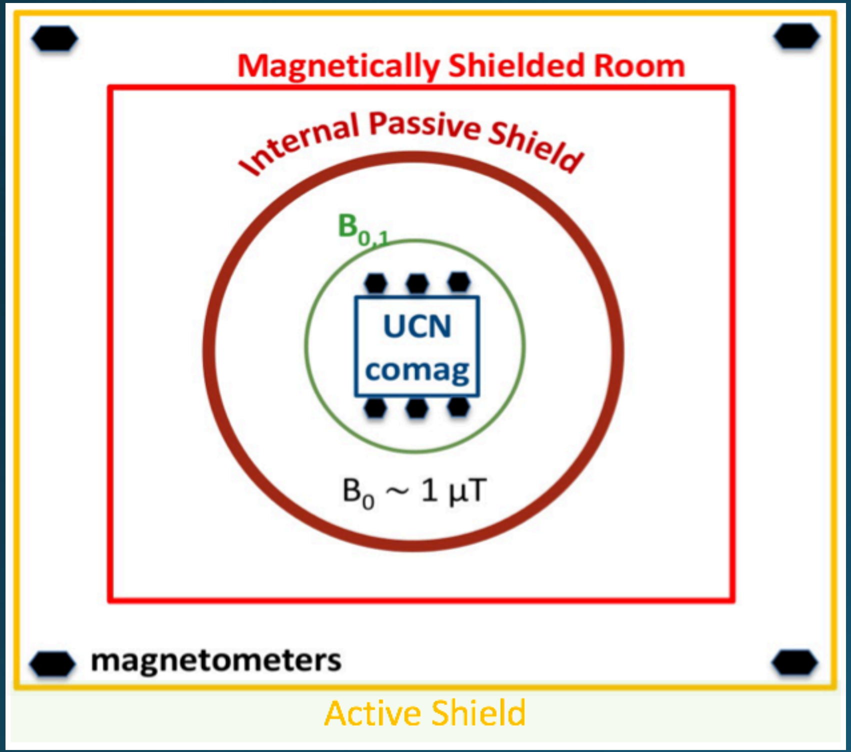
$$\boxed{d_n = \frac{h(\nu_{\uparrow\uparrow} - \nu_{\uparrow\downarrow})}{4E}}$$

# The UCN Facility at TRIUMF

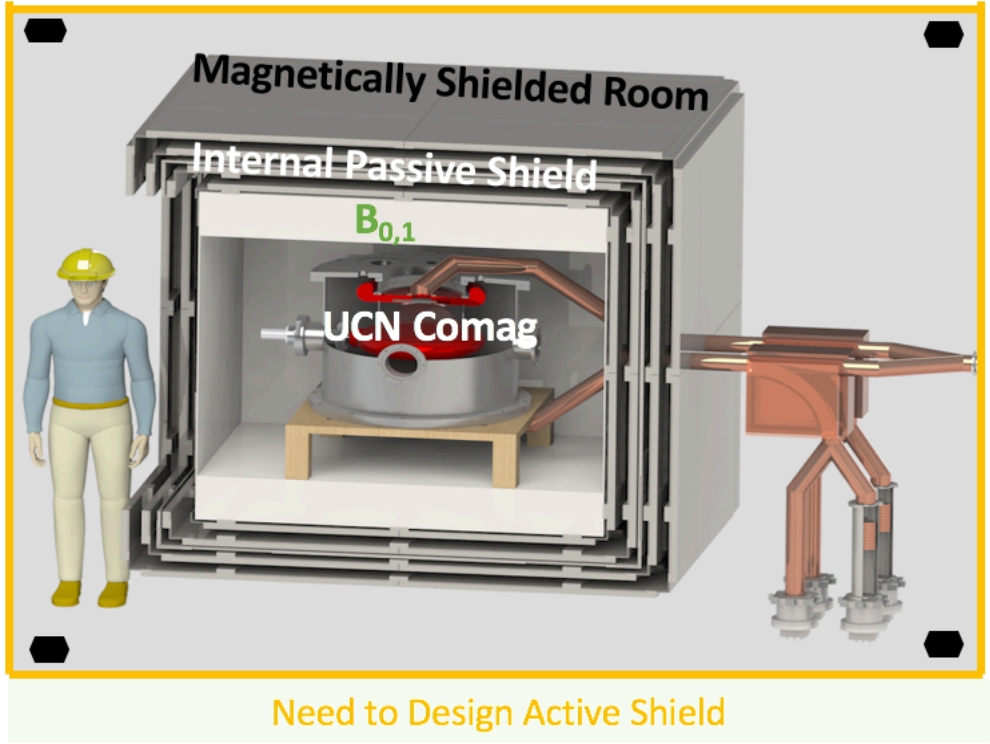


# Magnetic Field Compensation System

nEDM experiment requirements- $B_0$= 1 µT, **Stability** < pT & **Homogeneity** < nT/m



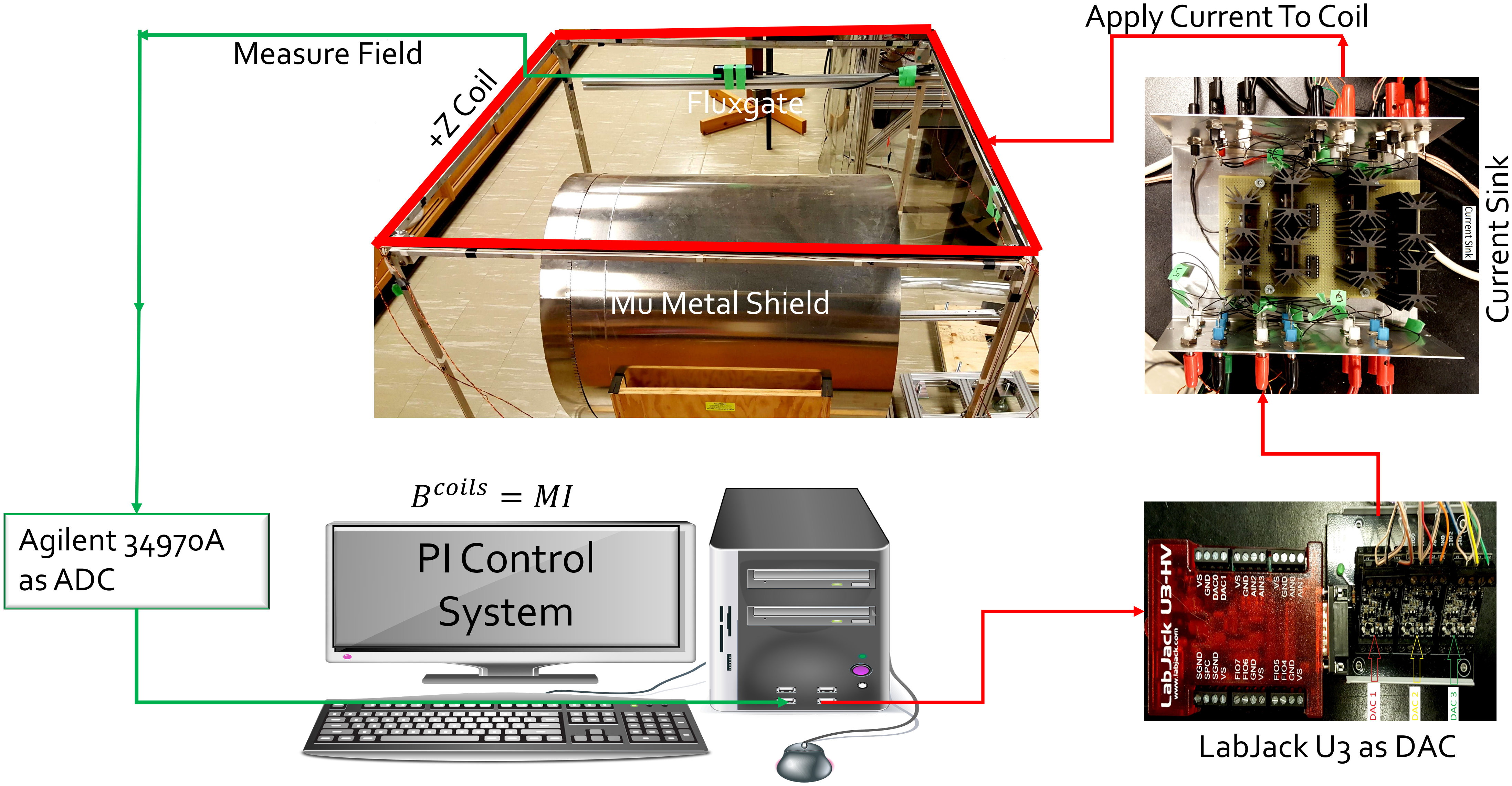
$B_{ext} \approx 400\ \mu T$



Active shield goals-

- Stability of field surrounding MSR ≤ 100 nT.
- Reduce 400 µT background (avoid saturation).
- Ability to open the door without magnetizing internal layers.

# Prototype Active Magnetic Field Compensation System at U of Winnipeg (One Dimensional Control)



Measure Field

+Z Coil

Fluxgate

Mu Metal Shield

Apply Current To Coil

Current Sink

Agilent 34970A as ADC

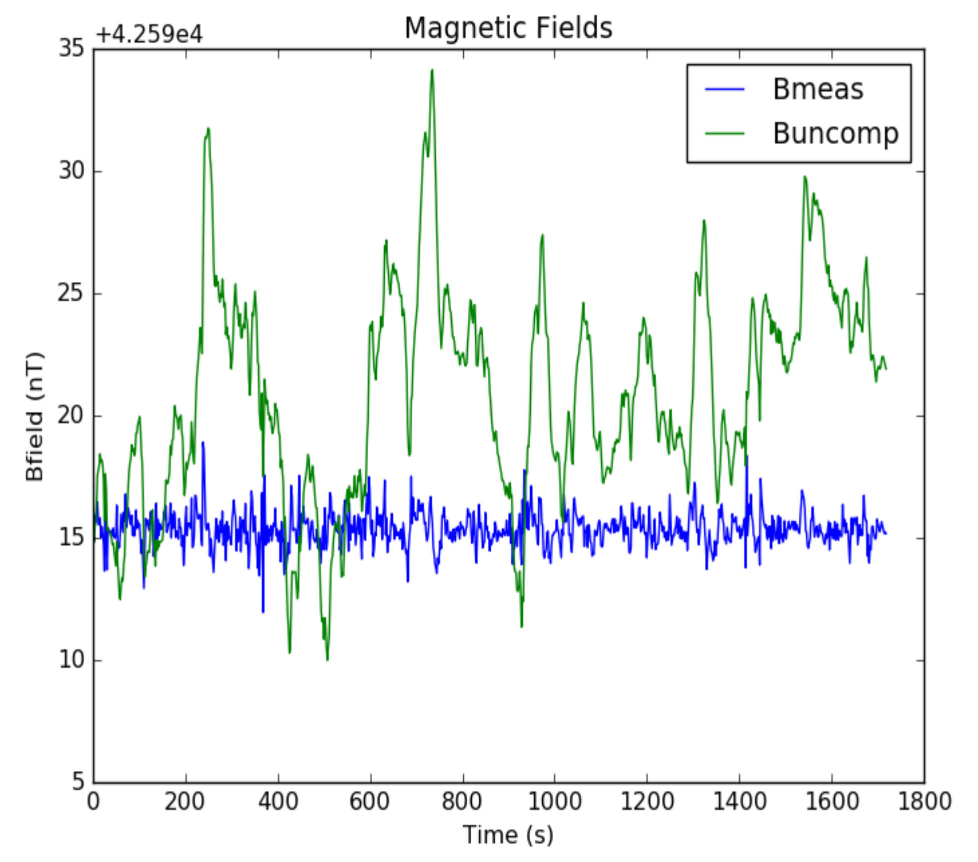
$$B^{coils} = MI$$

PI Control System

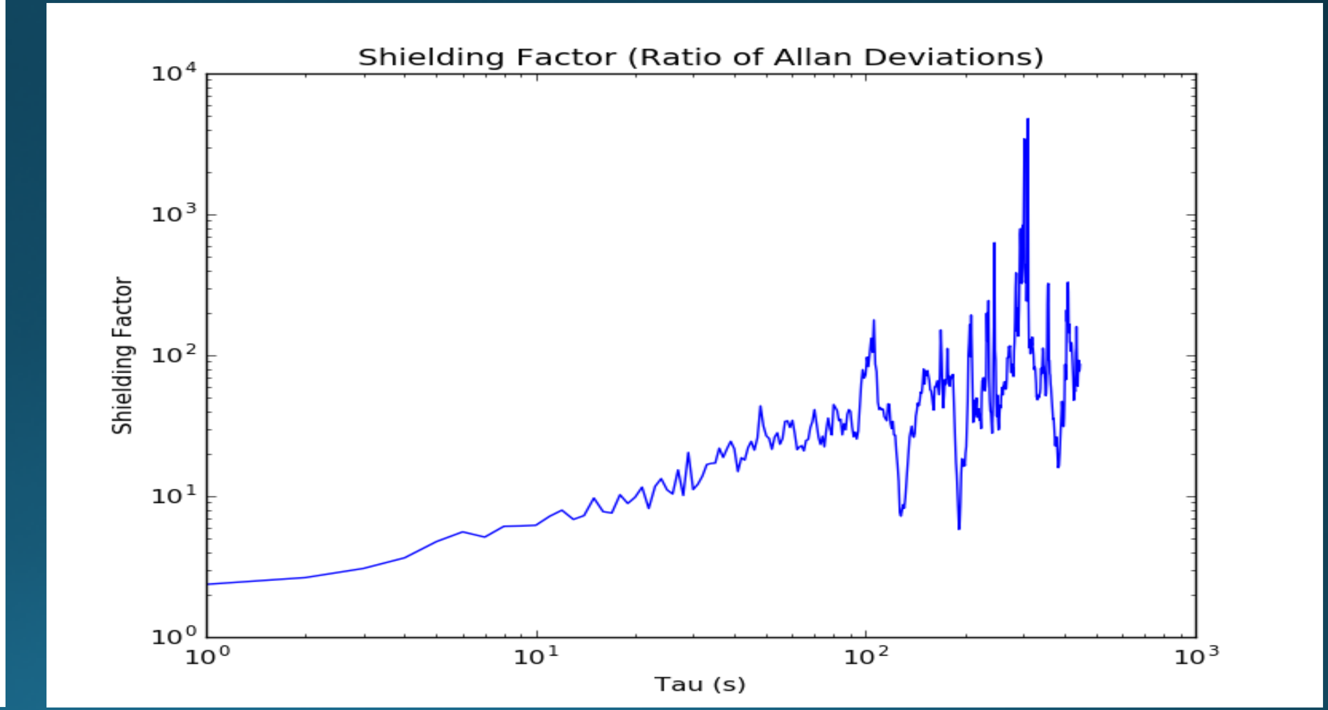
LabJack U3 as DAC

# One Dimensional Control Results

- $B_k^{meas} = B_k^{uncomp} + B_k^{coils}$



- Allan Deviation, $\sigma_{ADEV} = \sqrt{\frac{1}{2} < (y_{n+1} - y_n)^2 >}$
  - $y_n$ - nth average over $\tau$.
- Shielding Factor , $S_k(\tau) = \frac{\sigma_{ADEV}(B_k^{uncomp})}{\sigma_{ADEV}(B_k^{meas})}$

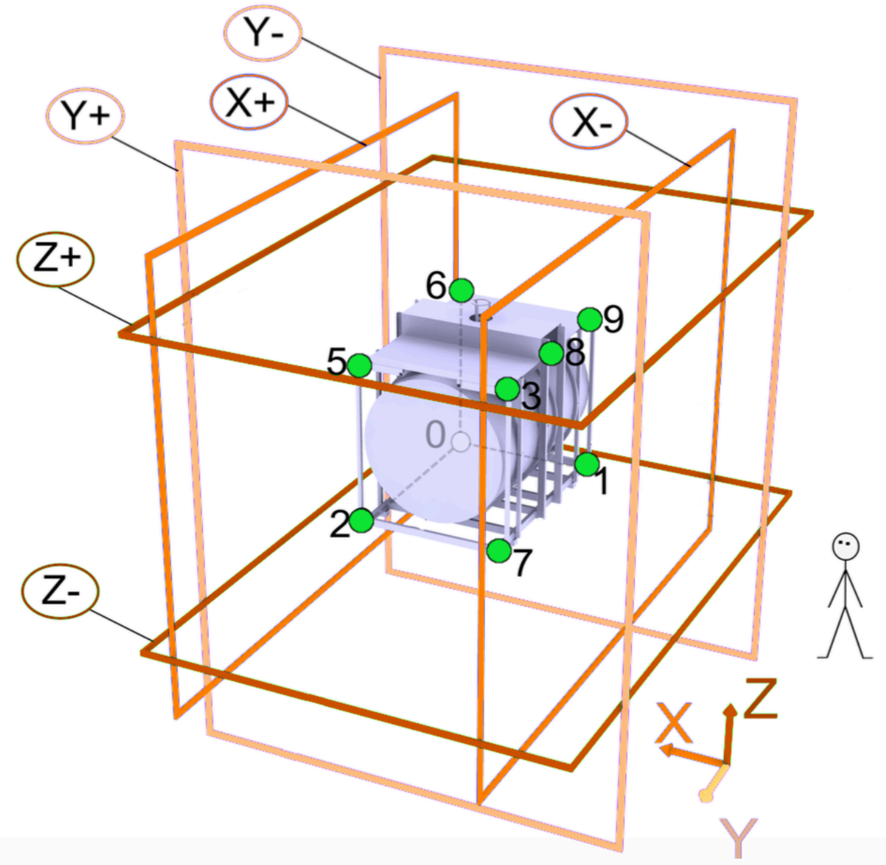


Shielding Factor > 1 indicates success.

# Multi-Dimensional Control

$$B_k^{coils} = \sum_j M_{kj}.I_j \;\rightarrow\; \Delta \mathrm{I}_j = \sum_j M_{jk}^{-1}.\left(B_k^{goal} - B_k^{meas}\right)$$

- Problem
  - Inverse of non-square matrix.
  - Wildly varying currents and poor control away from sensor positions.
- Solution*
  - Use pseudoinverse with Tikhonov regularization.
  - Regularization Parameter, r
    - $r \rightarrow -\infty$ means non regularized (big current fluctuations).
    - $r \rightarrow +\infty$ means $M^{-1} \rightarrow 0$ (no control).



* B. Franke, Doctoral Theses, ETH-Zürich (2013).

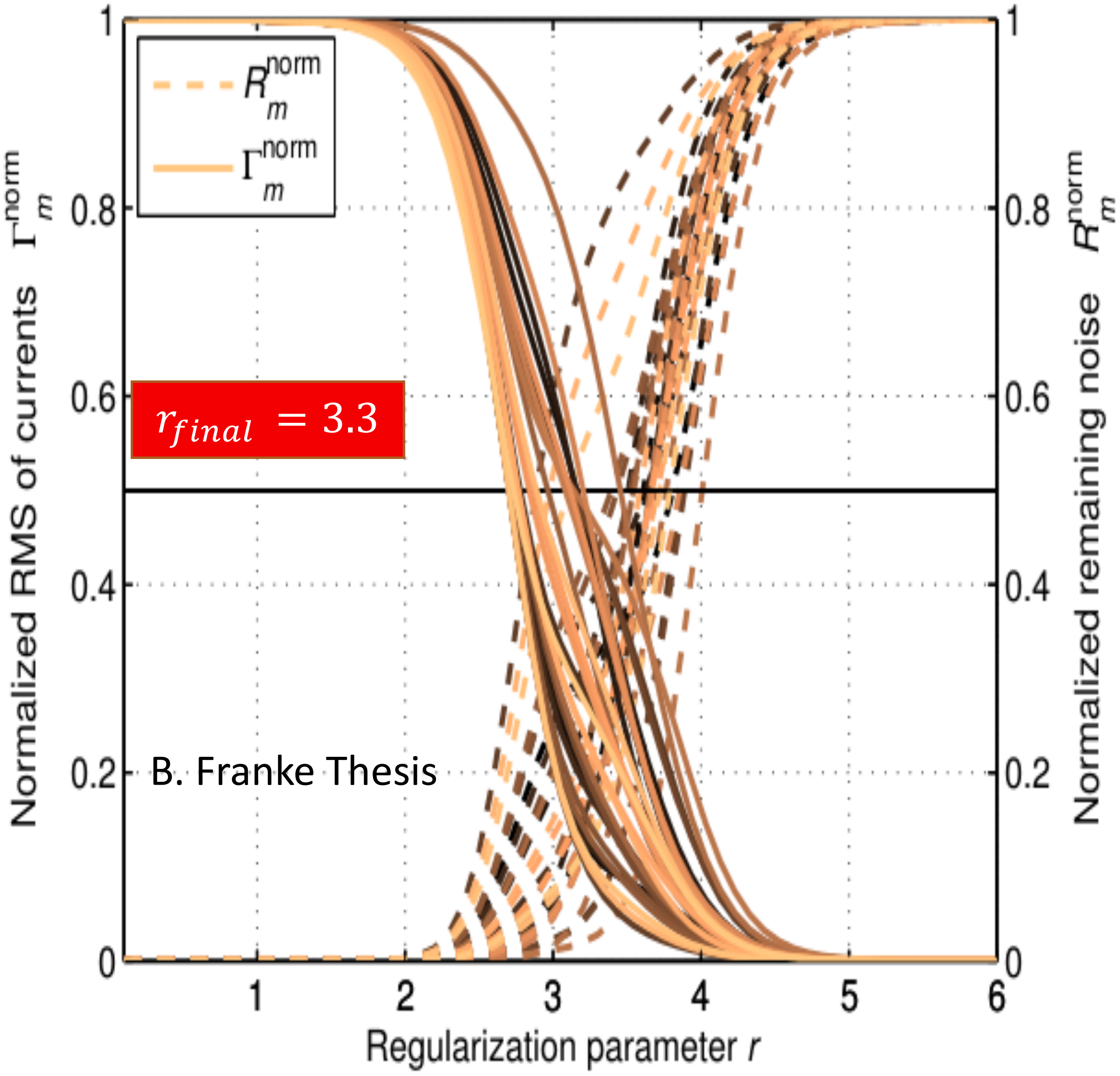
# Monte Carlo Method to Find $M^{-1}$

1. Generate “reasonable” random B at sensor positions.

2. Find the “best” value of r
   - Trading off small current fluctuations ($r \rightarrow +\infty$) against small magnitude field fluctuations ($r \rightarrow -\infty$).

3. Repeat for many different random B’s and average to find best r.

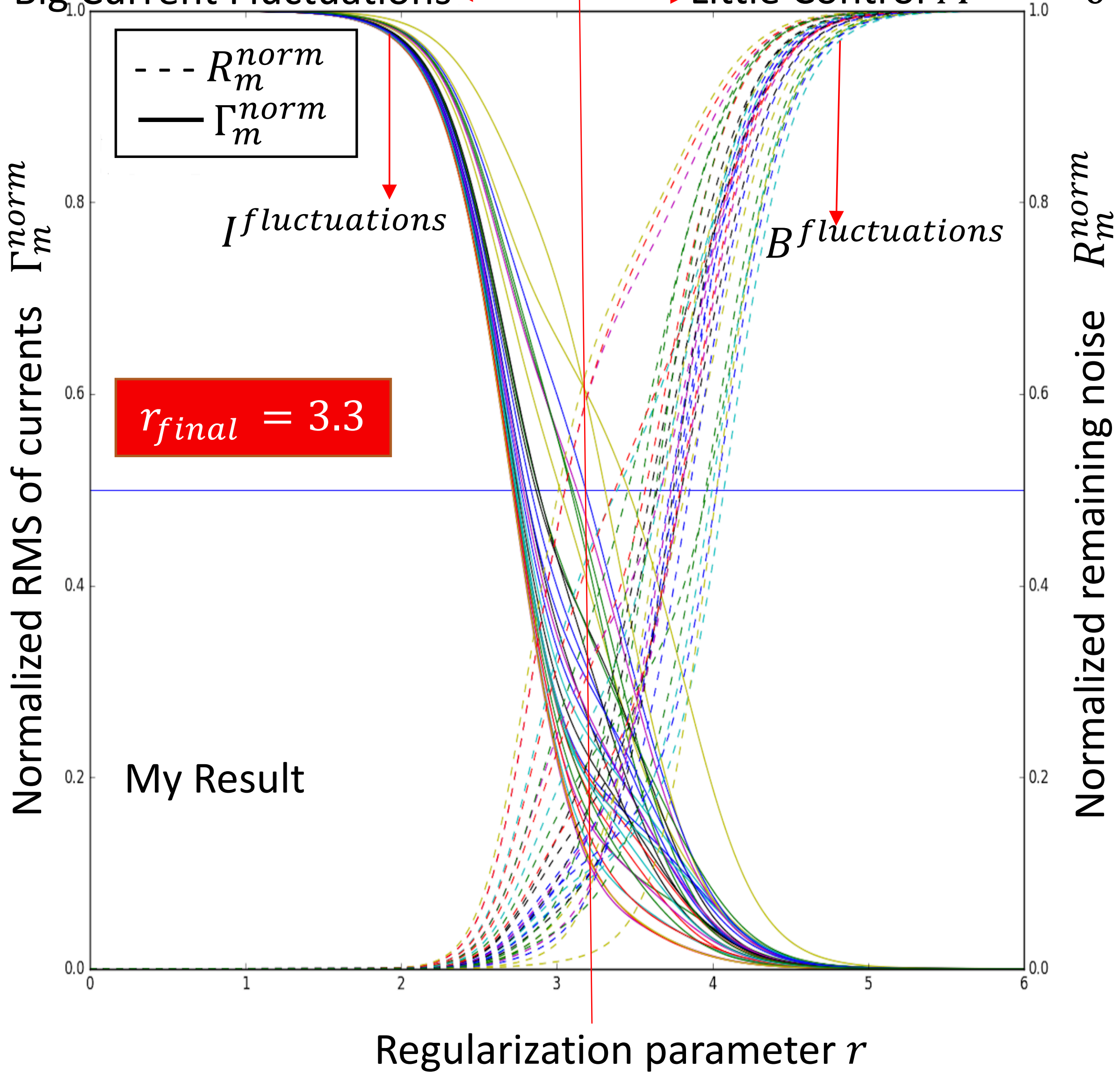
# Result



$r_{final} = 3.3$

B. Franke Thesis

Big Current Fluctuations ↔ Little Control $M^{-1} \rightarrow 0$



$r_{final} = 3.3$

My Result

Conclusion: Using matrix from B. Franke thesis, same r is found.

# Next Steps

- Build matrix $M$ for our system.
- Simulate shield and coils to determine the best positions for fluxgate.
- Design the DAQ to meet sampling rate, resolution and noise requirements.
- Study possibility of saturation and design accordingly.

# Conclusion

- Non-zero nEDM tests T-symmetry, new physics violating CP symmetry.
- TRIUMF nEDM sensitivity $10^{-27}$ e-cm in Phase 2 operations.
- nEDM experiment requires very stable (< pT) and homogeneous (< nT/m) magnetic field.
- Need suitable active magnetic compensation system.

# Thank You

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