Magnetic Shielding for the nEDM Experiment at TRIUMF

Michael Lang

The University of Manitoba and The University of Winnipeg

CAP Congress, 2014

University of Manitoba

The University of Winnipeg

TRIUMF

Table of Contents

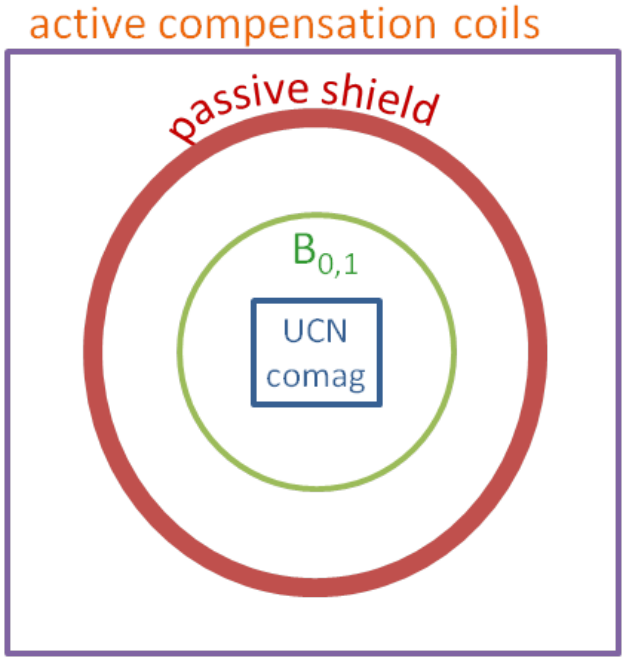
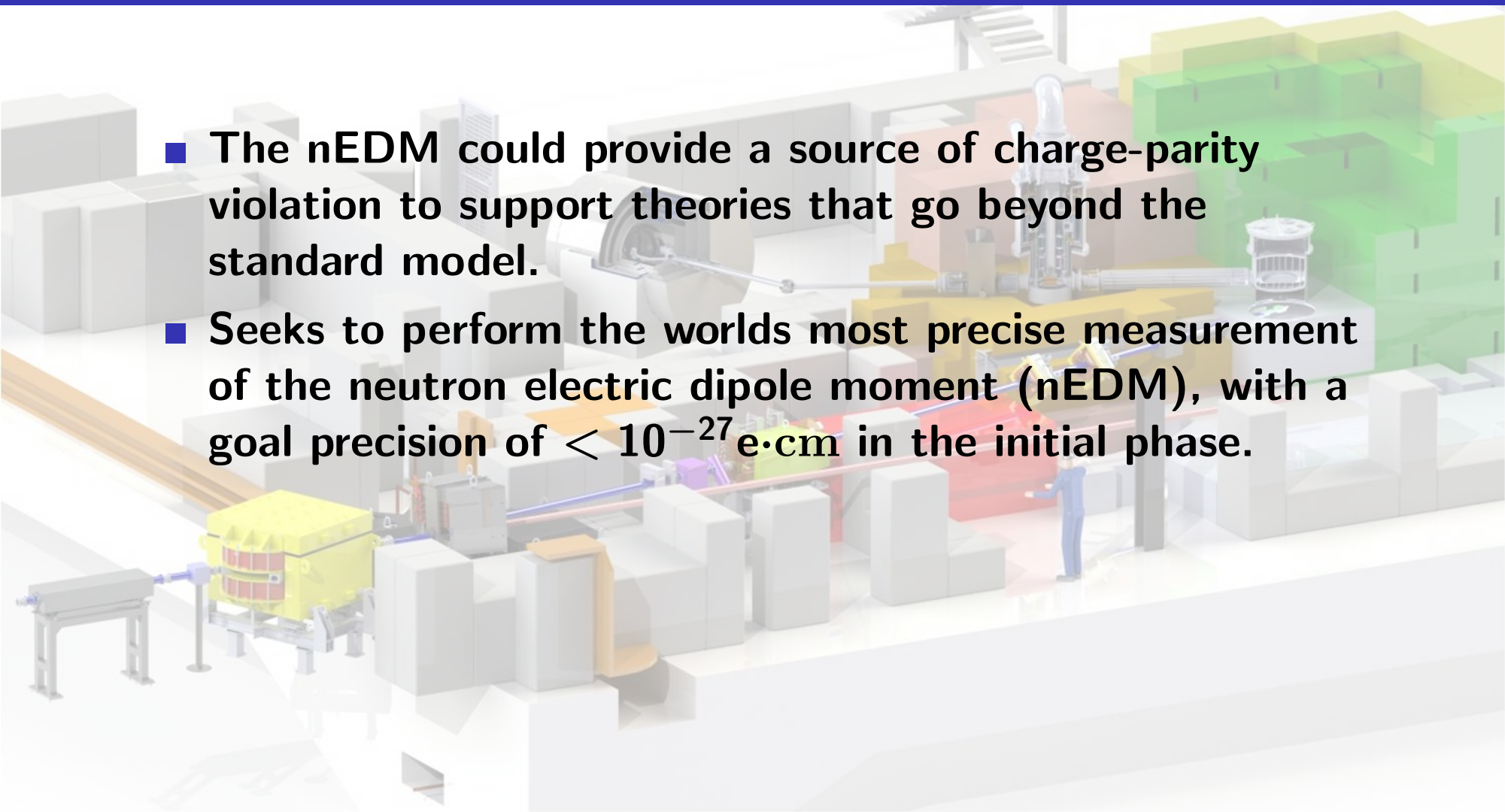


Table of Contents

The nEDM Experiment at TRIUMF

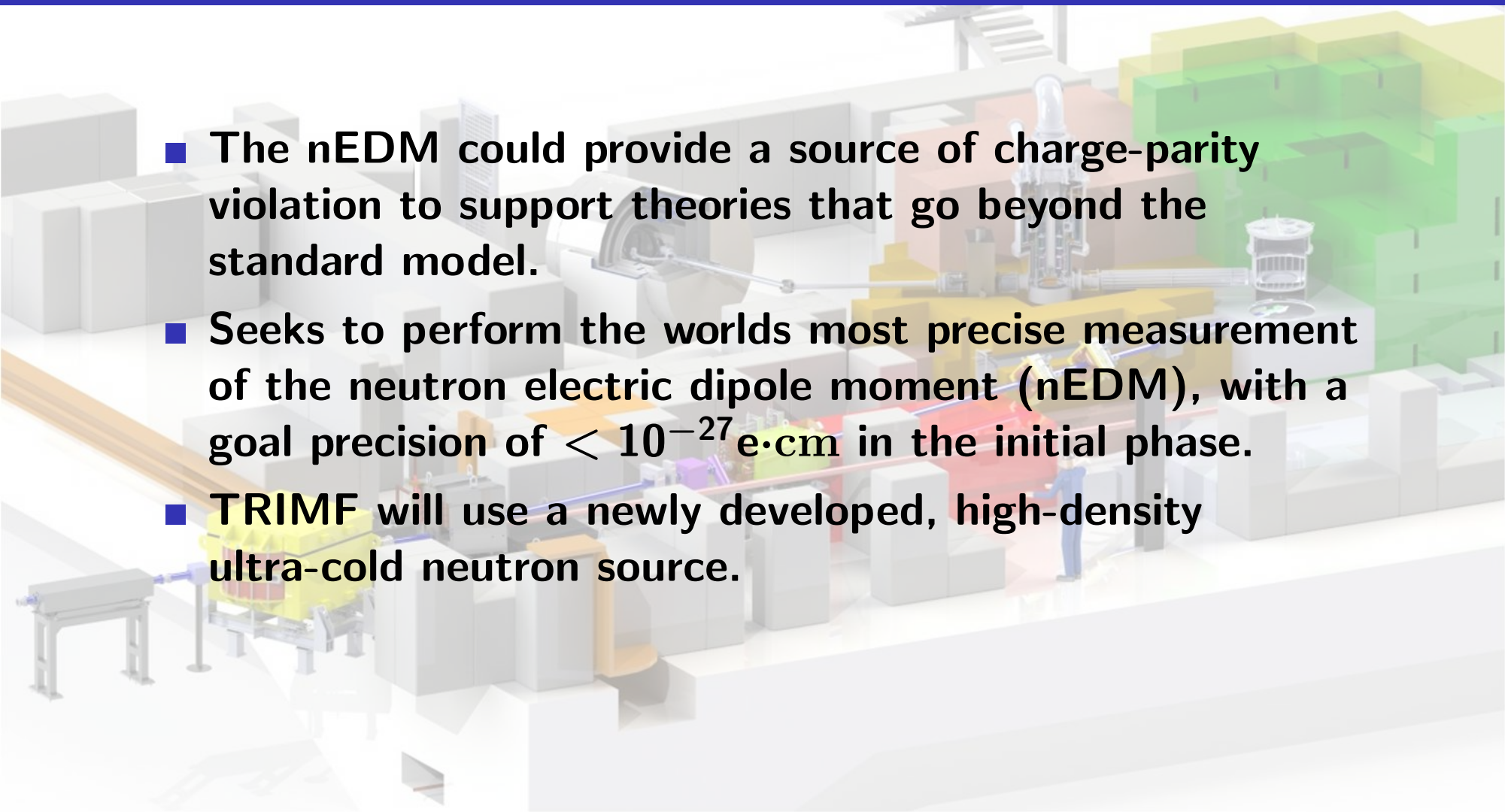
- **The nEDM could provide a source of charge-parity violation to support theories that go beyond the standard model.**

The nEDM Experiment at TRIUMF



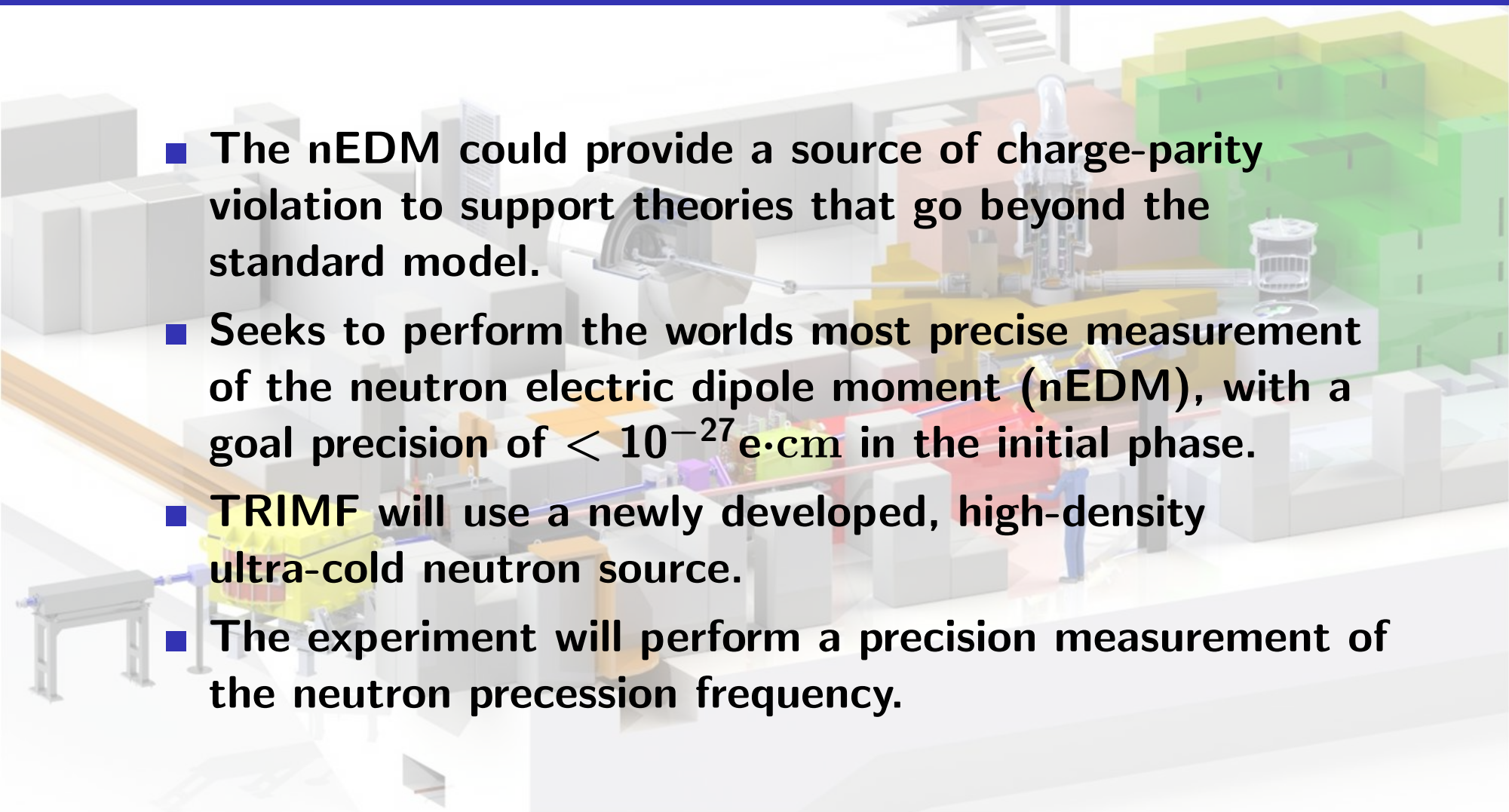
- **The nEDM could provide a source of charge-parity violation to support theories that go beyond the standard model.**
- **Seeks to perform the worlds most precise measurement of the neutron electric dipole moment (nEDM), with a goal precision of $< 10^{-27} \mathrm{e{\cdot}cm}$ in the initial phase.**

The nEDM Experiment at TRIUMF



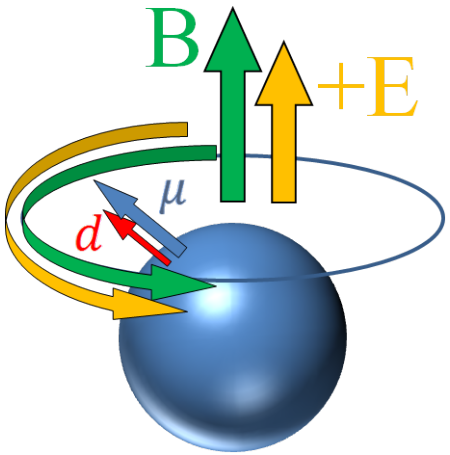
- **The nEDM could provide a source of charge-parity violation to support theories that go beyond the standard model.**
- **Seeks to perform the worlds most precise measurement of the neutron electric dipole moment (nEDM), with a goal precision of $< 10^{-27} \mathrm{e{\cdot}cm}$ in the initial phase.**
- **TRIMF will use a newly developed, high-density ultra-cold neutron source.**

The nEDM Experiment at TRIUMF



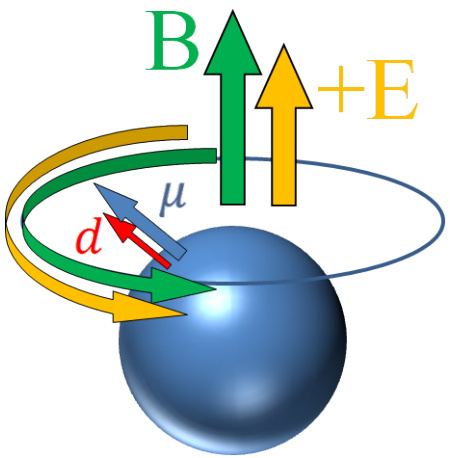
- **The nEDM could provide a source of charge-parity violation to support theories that go beyond the standard model.**
- **Seeks to perform the worlds most precise measurement of the neutron electric dipole moment (nEDM), with a goal precision of $< 10^{-27} \mathrm{e{\cdot}cm}$ in the initial phase.**
- **TRIMF will use a newly developed, high-density ultra-cold neutron source.**
- **The experiment will perform a precision measurement of the neutron precession frequency.**

Measuring an nEDM

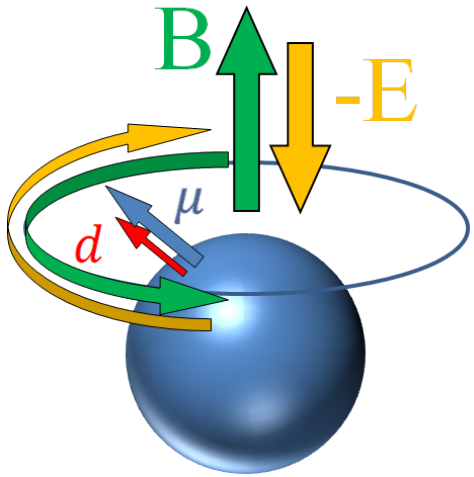


$$\hbar\omega_0^{\uparrow\uparrow} = |2\mu_n B_0 + 2d_n E|$$

Measuring an nEDM

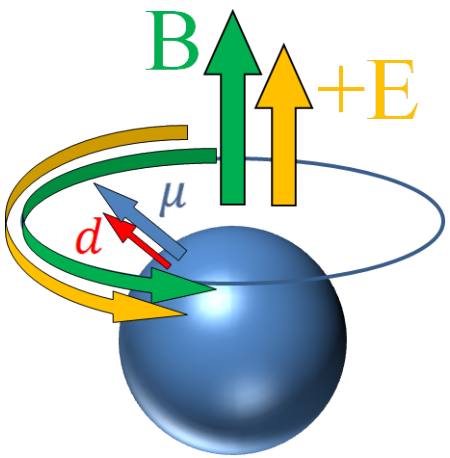


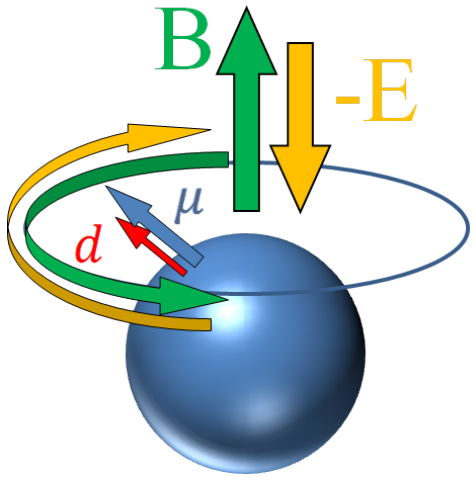
$$\hbar\omega_0^{\uparrow\uparrow} = |2\mu_n B_0 + 2d_n E|$$



$$\hbar\omega_0^{\uparrow\downarrow} = |2\mu_n B_0 - 2d_n E|$$

Measuring an nEDM

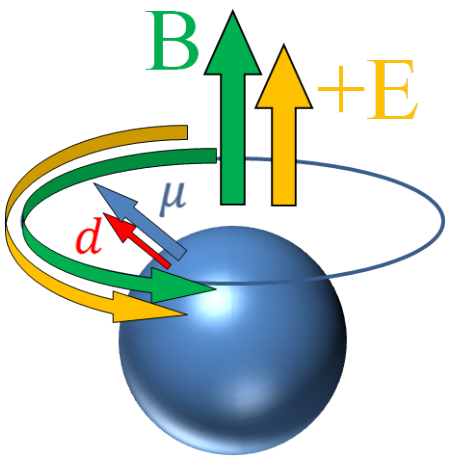


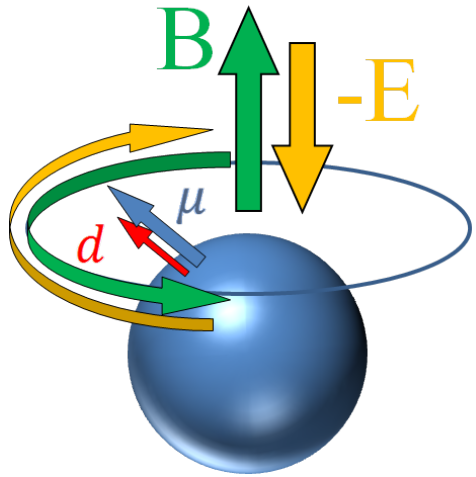


$$\hbar\omega_0^{\uparrow\uparrow} = |2\mu_n B_0 + 2d_n E| \qquad \hbar\omega_0^{\uparrow\downarrow} = |2\mu_n B_0 - 2d_n E|$$

$$\Rightarrow d_n = \frac{\hbar(\omega_0^{\uparrow\uparrow} - \omega_0^{\uparrow\downarrow})}{4E}$$

Measuring an nEDM





$$\hbar\omega_0^{\uparrow\uparrow} = |2\mu_n B_0 + 2d_n E| \qquad \hbar\omega_0^{\uparrow\downarrow} = |2\mu_n B_0 - 2d_n E|$$

$$\Rightarrow d_n = \frac{\hbar(\omega_0^{\uparrow\uparrow} - \omega_0^{\uparrow\downarrow})}{4E}$$

Current best experimental upper limit on the neutron EDM is

$$|d_n| < 2.9 \times 10^{-26} e \cdot \mathrm{cm}$$ (Baker et al. PRL 97, 131801 (2006))

Requirements for magnetic shielding at TRIUMF

- Background external field at TRIUMF in the experimental location is of order 350 μT.

Requirements for magnetic shielding at TRIUMF

- Background external field at TRIUMF in the experimental location is of order 350 μT.
- We require a B_0 field of $\approx 1\mu$T.

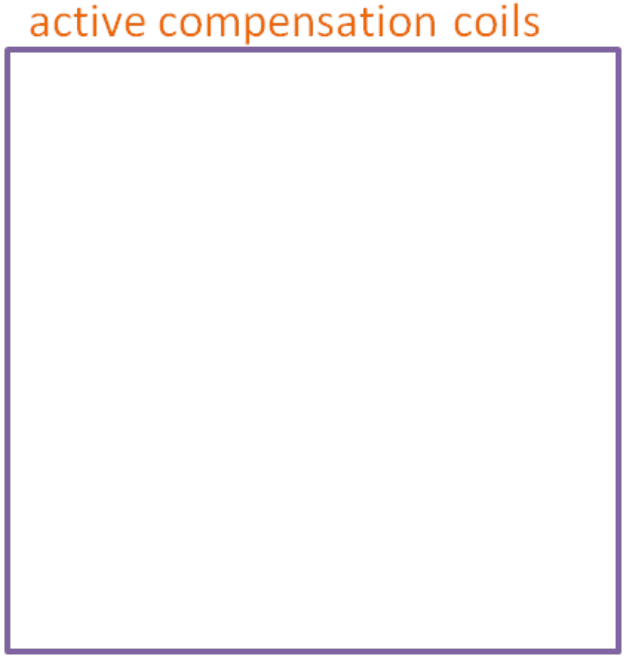
Requirements for magnetic shielding at TRIUMF

- Background external field at TRIUMF in the experimental location is of order 350 μT.
- We require a B_0 field of $\approx 1\mu$T.
- Field gradients in the experimental volume must be < 1 nT/m

Requirements for magnetic shielding at TRIUMF

- Background external field at TRIUMF in the experimental location is of order 350 μT.
- We require a B_0 field of $\approx 1\mu$T.
- Field gradients in the experimental volume must be < 1 nT/m
- Field fluctuations over the course of one experimental cycle must be $<$ 1pT.

Table of Contents



The Active Magnetic Shield

- Eliminates slow background field drifts (order 10 Hz).

The Active Magnetic Shield

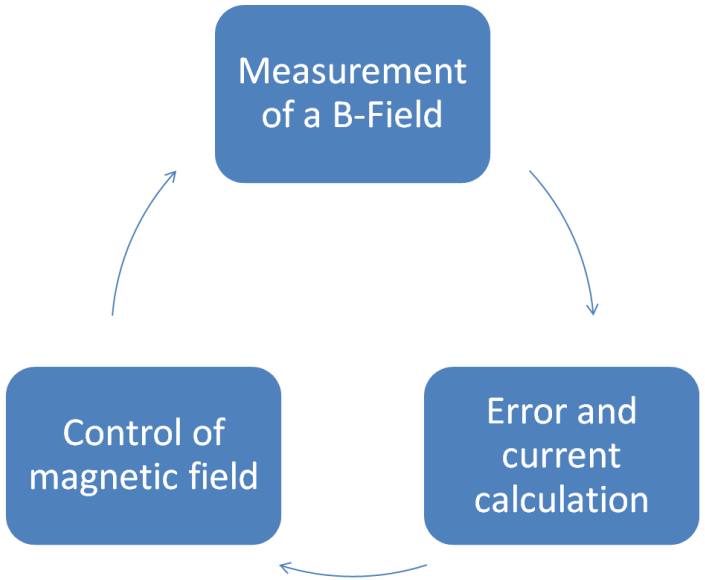
- Eliminates slow background field drifts (order 10 Hz).
- Reduces the background field amplitude to assist passive shielding.

The Active Magnetic Shield

- Eliminates slow background field drifts (order 10 Hz).
- Reduces the background field amplitude to assist passive shielding.
- Provides information about background field drifts.

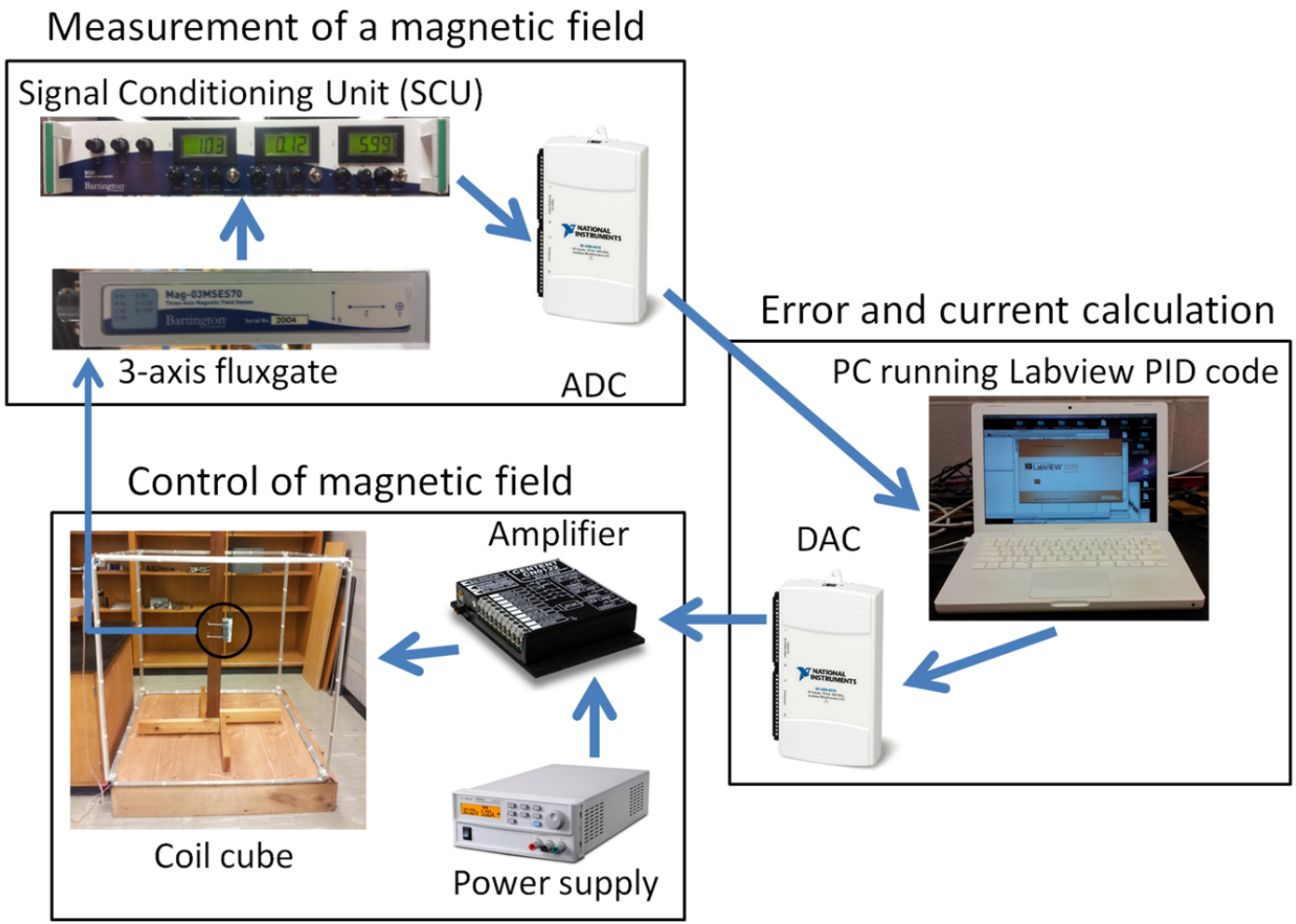
The Active Magnetic Shield

- Eliminates slow background field drifts (order 10 Hz).
- Reduces the background field amplitude to assist passive shielding.
- Provides information about background field drifts.
- Operates under a feedback control loop.



Control Loop of the prototype active shielding system

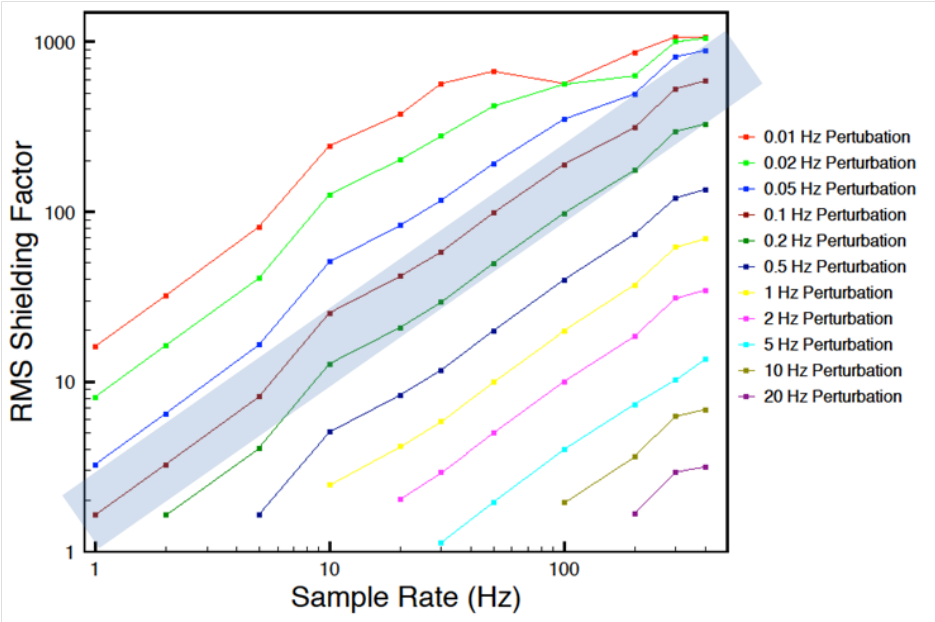
M. Lang M.Sc. Thesis http://hdl.handle.net/1993/23223



Prototype active shielding system performance

M. Lang M.Sc. Thesis http://hdl.handle.net/1993/23223

- Active shielding factors ≥ 1000 are achievable for a single axis.

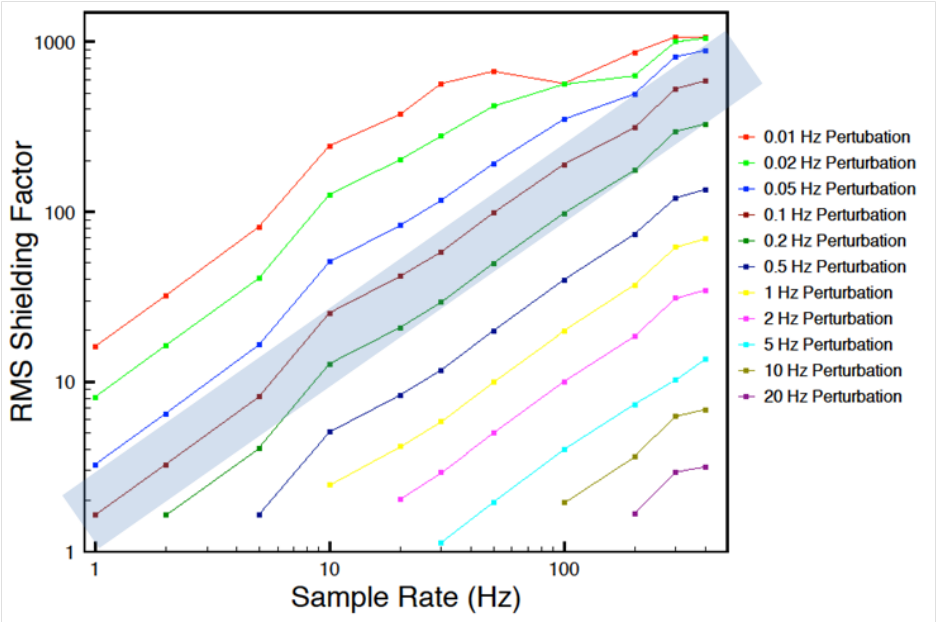


Active shielding study at University of Winnipeg

Prototype active shielding system performance

M. Lang M.Sc. Thesis http://hdl.handle.net/1993/23223

- Active shielding factors ≥ 1000 are achievable for a single axis.
- Shielding factor is proportional to the field sampling rate.

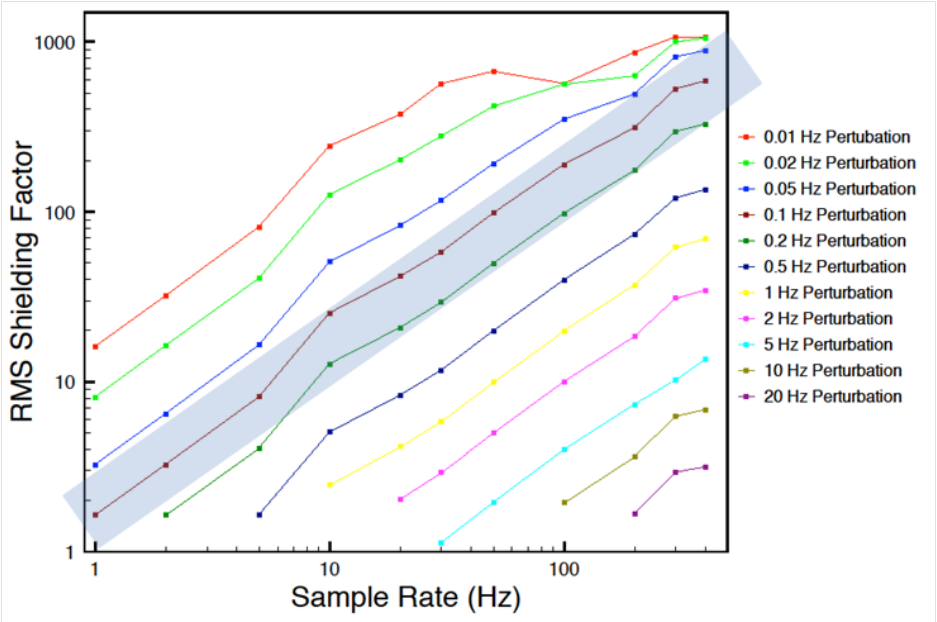


Active shielding study at University of Winnipeg

Prototype active shielding system performance

M. Lang M.Sc. Thesis http://hdl.handle.net/1993/23223

- Active shielding factors ≥ 1000 are achievable for a single axis.
- Shielding factor is proportional to the field sampling rate.
- Shielding factor is inversely proportional to the field perturbation amplitude.

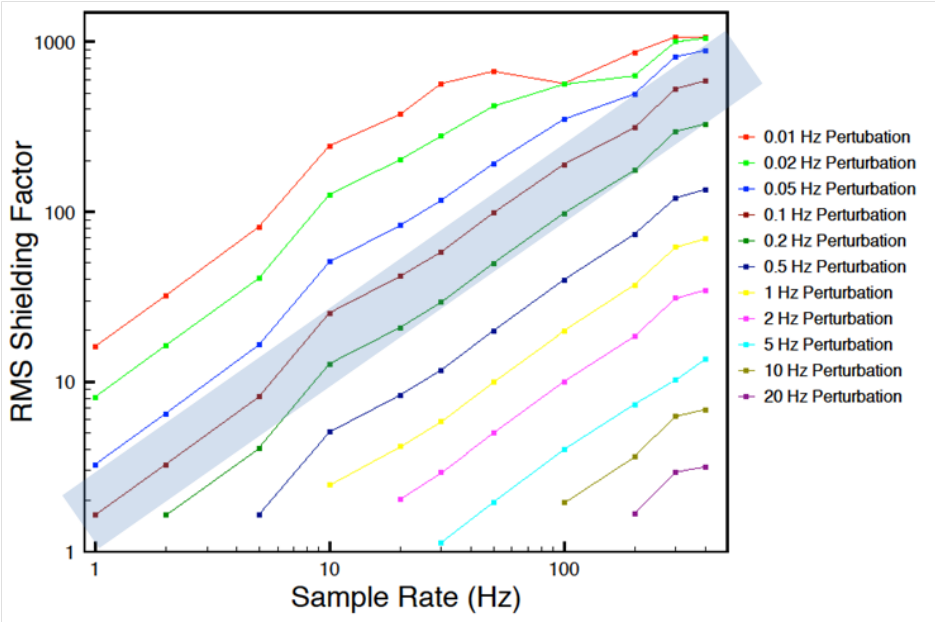


Active shielding study at University of Winnipeg

Prototype active shielding system performance

M. Lang M.Sc. Thesis http://hdl.handle.net/1993/23223

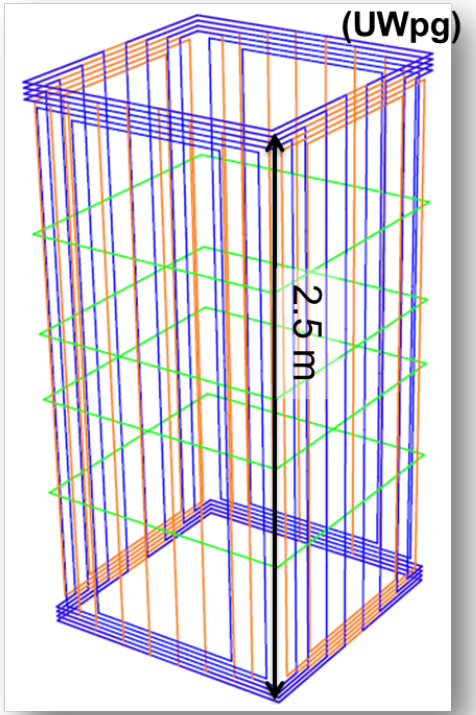
- Active shielding factors ≥ 1000 are achievable for a single axis.
- Shielding factor is proportional to the field sampling rate.
- Shielding factor is inversely proportional to the field perturbation amplitude.
- Present limits are the field sampling rate and the background noise (60-Hz dominated).



Active shielding study at University of Winnipeg

Future work for active shielding

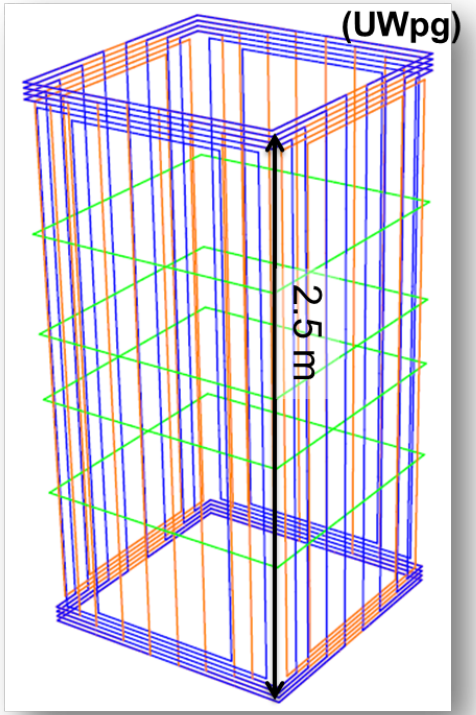
- Extend present single-axis prototype to a 3-axis system.



Model of the future active shielding coil system. (C. Loftson, UWinnipeg)

Future work for active shielding

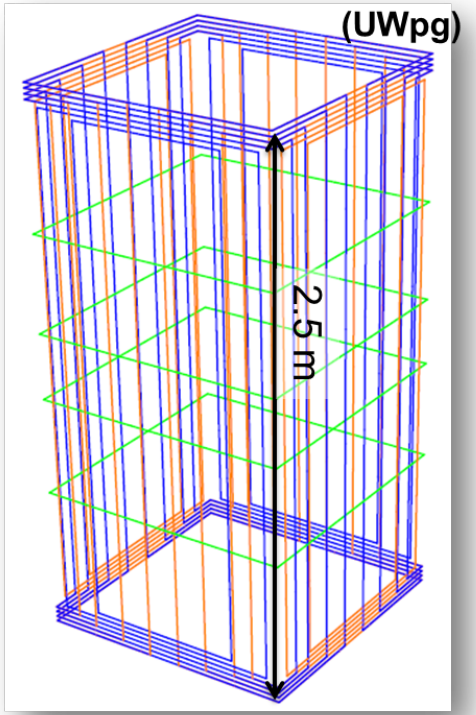
- Extend present single-axis prototype to a 3-axis system.
- Improve the sampling rate by introducing better electronics and data acquisition.



Model of the future active shielding coil system. (C. Loftson, UWinnipeg)

Future work for active shielding

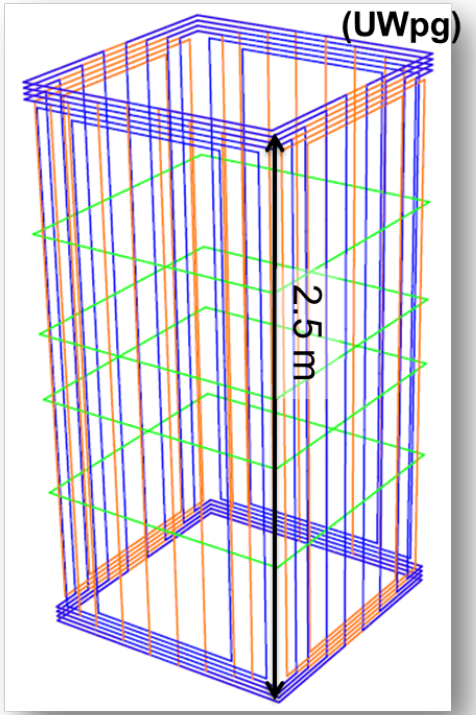
- Extend present single-axis prototype to a 3-axis system.
- Improve the sampling rate by introducing better electronics and data acquisition.
- Reduce background noise with shielding or electronic filters.



Model of the future active shielding coil system. (C. Loftson, UWinnipeg)

Future work for active shielding

- Extend present single-axis prototype to a 3-axis system.
- Improve the sampling rate by introducing better electronics and data acquisition.
- Reduce background noise with shielding or electronic filters.
- Scale the prototype for use in the TRIUMF nEDM experiment.

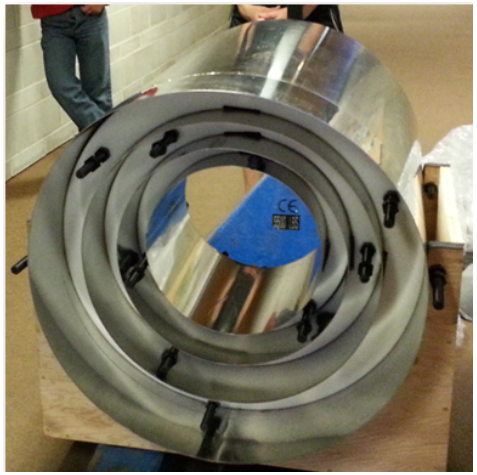


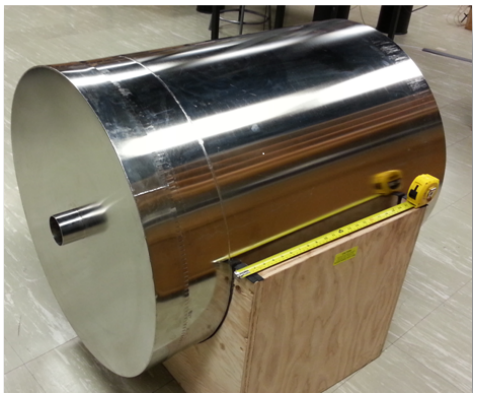
Model of the future active shielding coil system. (C. Loftson, UWinnipeg)

Table of Contents

Passive shield prototype at the University of Winnipeg

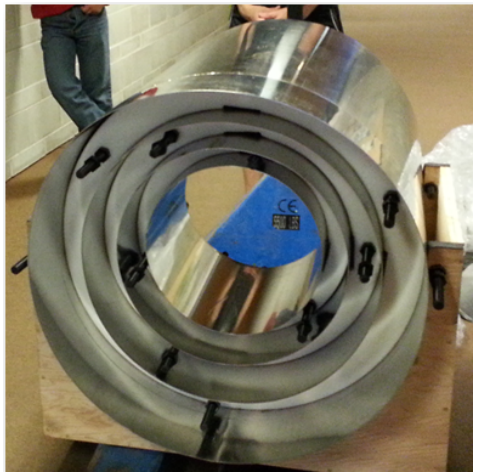
- Located within the active shield

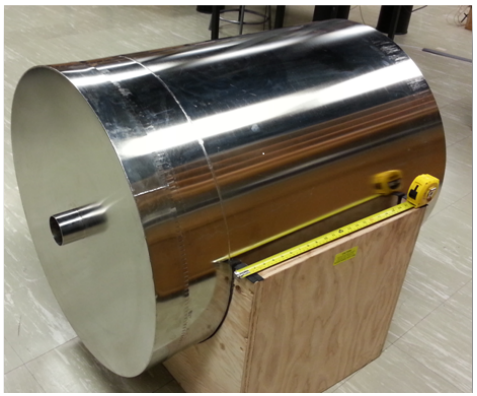




Passive shield prototype at the University of Winnipeg

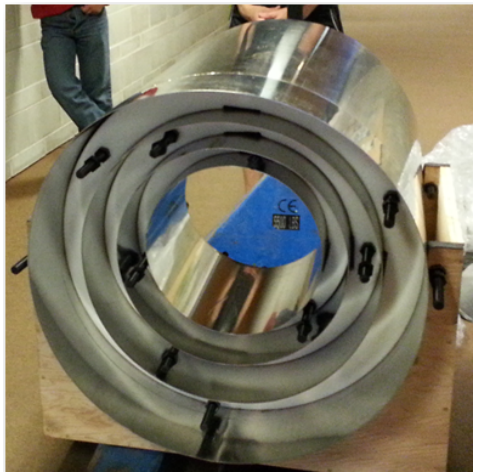
- Located within the active shield
- Four-concentric cylindrical layers.

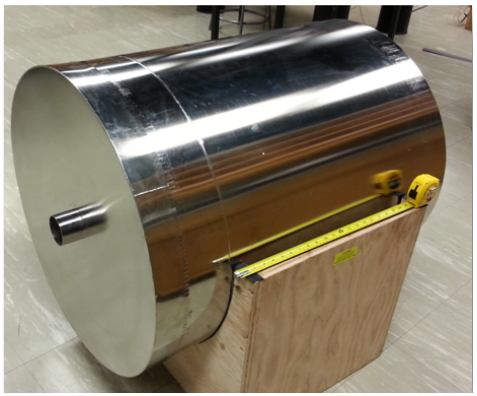




Passive shield prototype at the University of Winnipeg

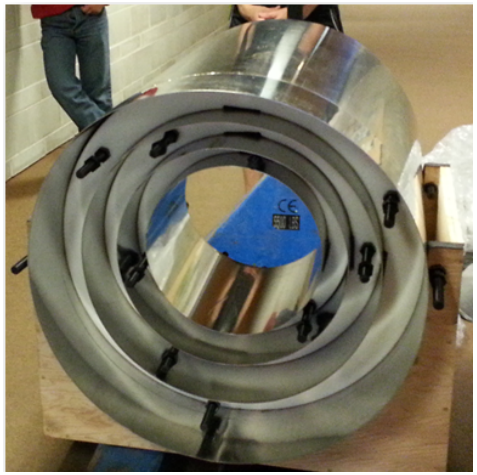
- Located within the active shield
- Four-concentric cylindrical layers.
- Constructed from high-permeability metal (μ-metal).

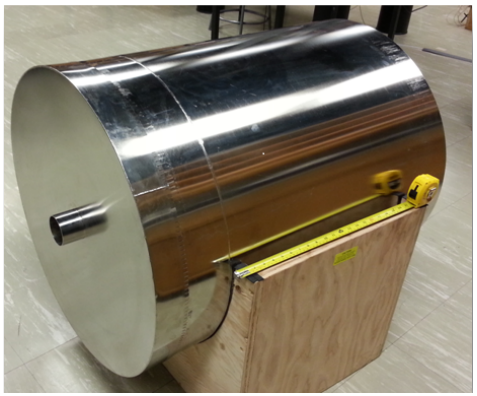




Passive shield prototype at the University of Winnipeg

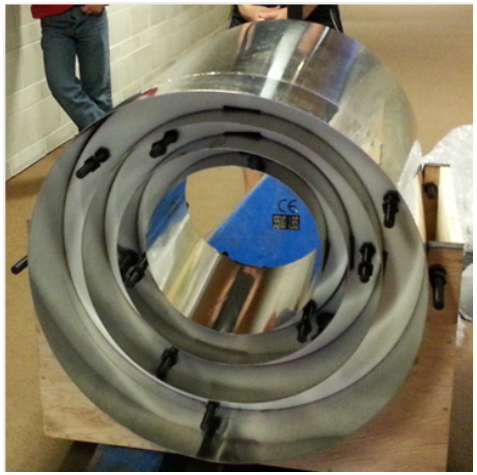
- Located within the active shield
- Four-concentric cylindrical layers.
- Constructed from high-permeability metal (μ-metal).
- Endcaps with stovepipe access to the center.

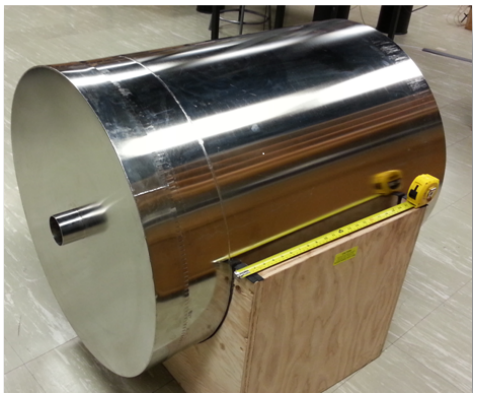




Passive shield prototype at the University of Winnipeg

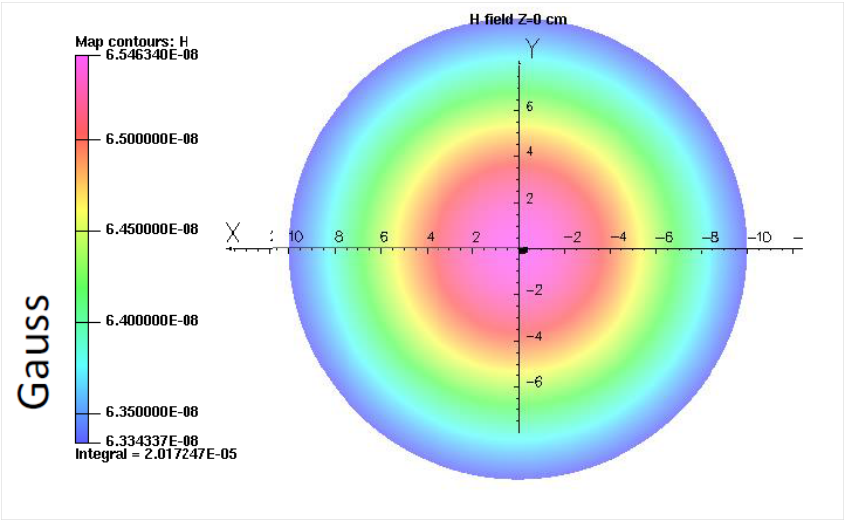
- Located within the active shield
- Four-concentric cylindrical layers.
- Constructed from high-permeability metal (μ-metal).
- Endcaps with stovepipe access to the center.
- Scalable for use at TRIUMF in future nEDM experiment.





Simulation and field mapping of the passive shield

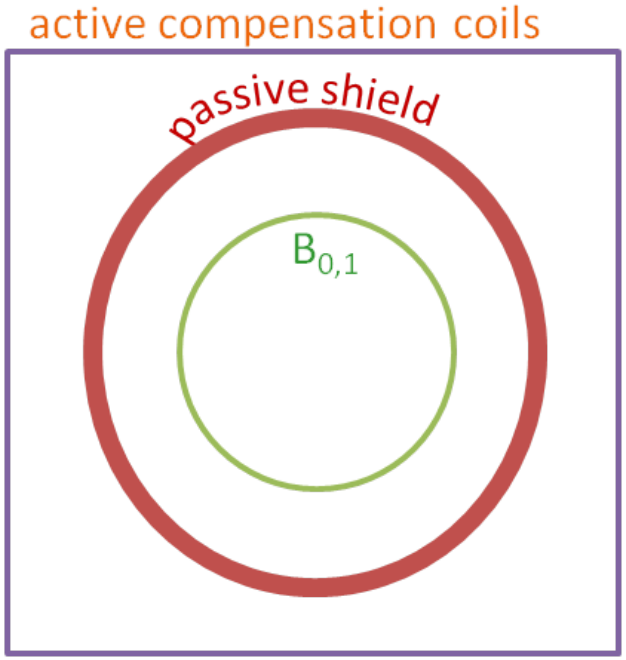
- Simulations in Opera give an axial shielding factor of $\approx 7 \times 10^6$ at the center (R. Mammei).



Simulation and field mapping of the passive shield

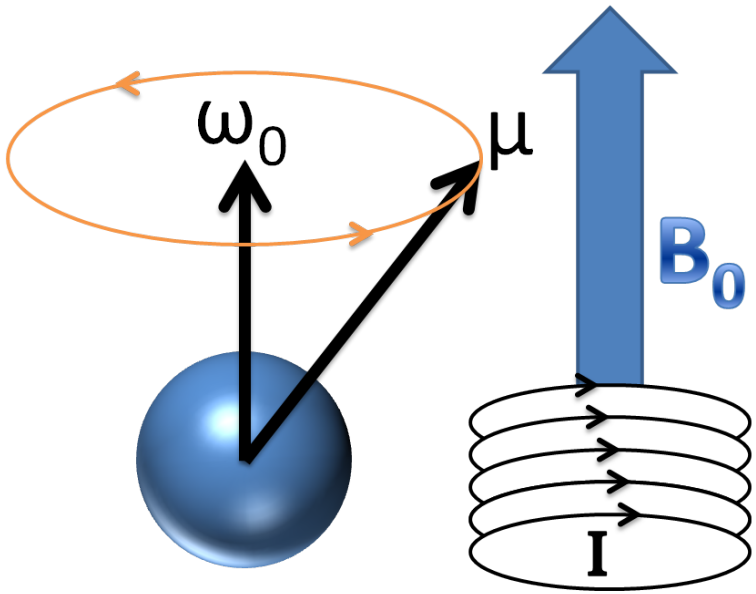
- Simulations in Opera give an axial shielding factor of $\approx 7 \times 10^6$ at the center (R. Mammei).
- Field mapper presently in development at University of Winnipeg (A. Harrison, UW summer student).

Table of Contents



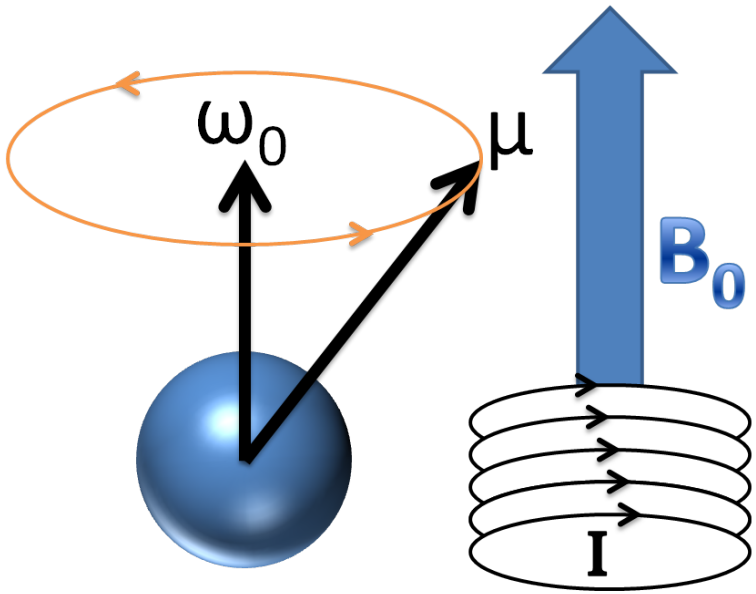
Purpose of the B_0 coil

- Located within the inner-most passive shield



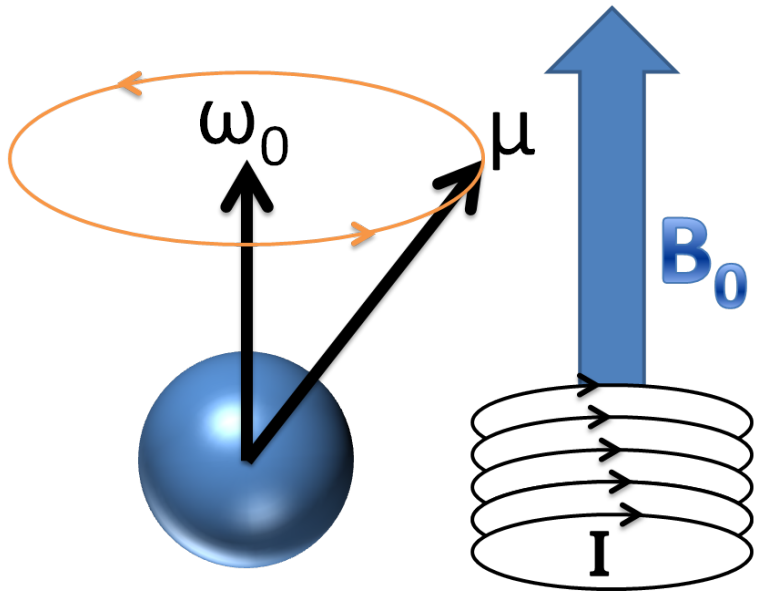
Purpose of the B_0 coil

- Located within the inner-most passive shield
- Produces the B_0 field, which sets the precession frequency ω_0 of the atomic species under observation.



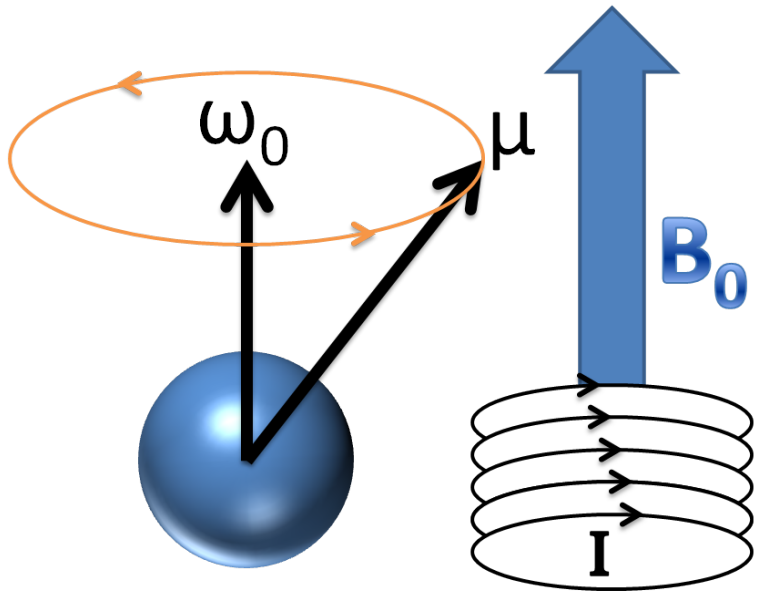
Purpose of the B_0 coil

- Located within the inner-most passive shield
- Produces the B_0 field, which sets the precession frequency ω_0 of the atomic species under observation.
- Precession frequency is given by the Larmor equation $\omega_0 = \gamma B_0$, γ being the gyromagnetic ratio of the atomic species.



Purpose of the B_0 coil

- Located within the inner-most passive shield
- Produces the B_0 field, which sets the precession frequency ω_0 of the atomic species under observation.
- Precession frequency is given by the Larmor equation $\omega_0 = \gamma B_0$, γ being the gyromagnetic ratio of the atomic species.
- The B_0 field should be homogeneous over the volume of the sample to reduce geometric phase effects, which result in systematic errors.



The present B_0 coil at University of Winnipeg

- To increase the B_0 field uniformity, the B_0 coil is shield coupled to the inner most passive shielding layer.

The present B_0 coil at University of Winnipeg

- To increase the B_0 field uniformity, the B_0 coil is shield coupled to the inner most passive shielding layer.
- The ideal case is a sheet solenoid type coil, within a closed cylindrical shield of infinite permeability (μ).

The present B_0 coil at University of Winnipeg

- To increase the B_0 field uniformity, the B_0 coil is shield coupled to the inner most passive shielding layer.
- The ideal case is a sheet solenoid type coil, within a closed cylindrical shield of infinite permeability (μ).
- Opera simulations were performed to investigate a discretized solenoid within a cylindrical shield with stovepipe end caps (P. Sarte, UWinnipeg student).

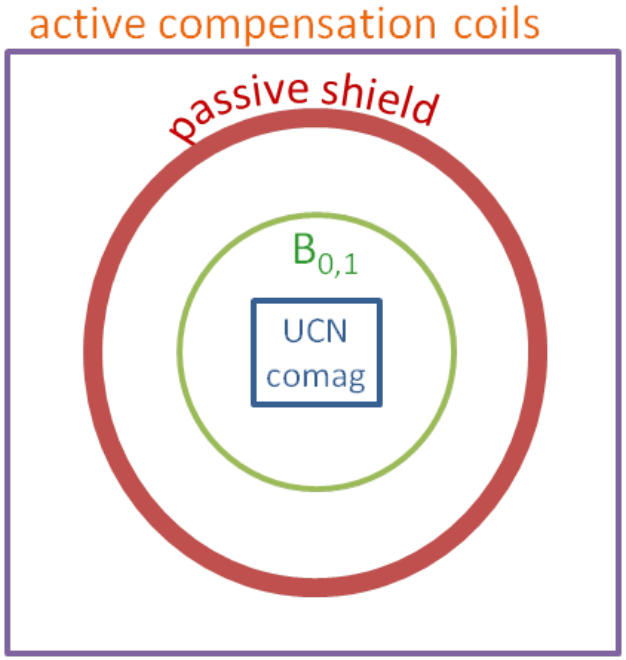
The present B_0 coil at University of Winnipeg

- To increase the B_0 field uniformity, the B_0 coil is shield coupled to the inner most passive shielding layer.
- The ideal case is a sheet solenoid type coil, within a closed cylindrical shield of infinite permeability (μ).
- Opera simulations were performed to investigate a discretized solenoid within a cylindrical shield with stovepipe end caps (P. Sarte, UWinnipeg student).
- The results showed that to achieve the desired field uniformity within the central region of the coil, we require $\mu \approx 20000$, which is achieved with our present active shield fabrication process.

The present B_0 coil at University of Winnipeg

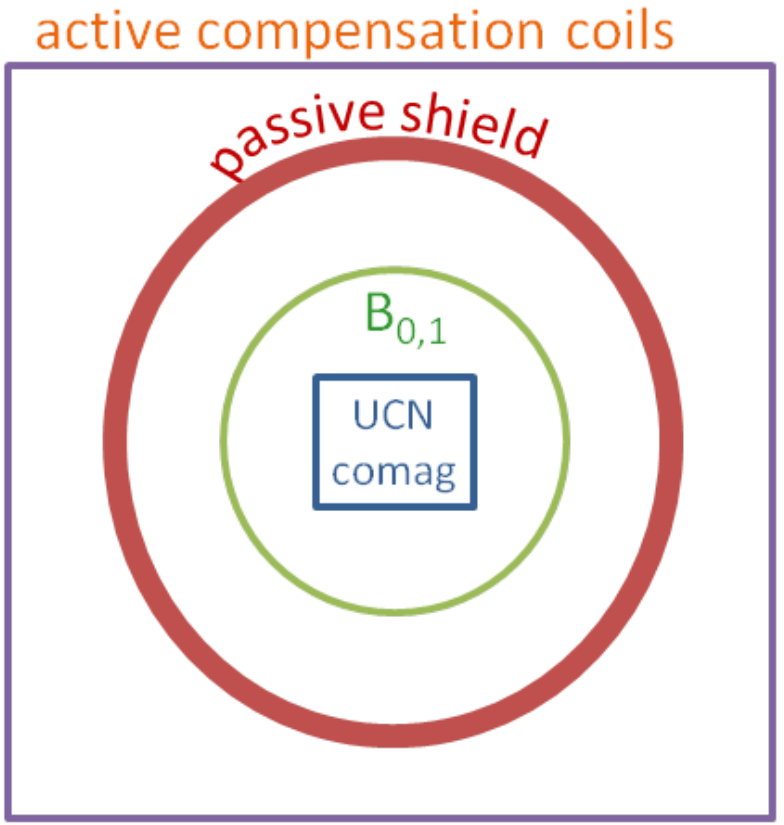
- To increase the B_0 field uniformity, the B_0 coil is shield coupled to the inner most passive shielding layer.
- The ideal case is a sheet solenoid type coil, within a closed cylindrical shield of infinite permeability (μ).
- Opera simulations were performed to investigate a discretized solenoid within a cylindrical shield with stovepipe end caps (P. Sarte, UWinnipeg student).
- The results showed that to achieve the desired field uniformity within the central region of the coil, we require $\mu \approx 20000$, which is achieved with our present active shield fabrication process.
- A prototype B_0 coil has been fabricated, and is presently being tested at the University of Winnipeg.

Table of Contents



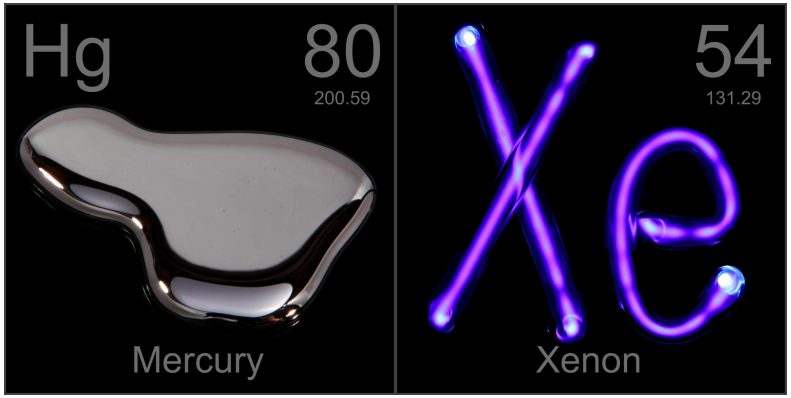
Co-magnetometer

- Located within the UCN cell at the center of the passive and active shields and the B_0 coil.



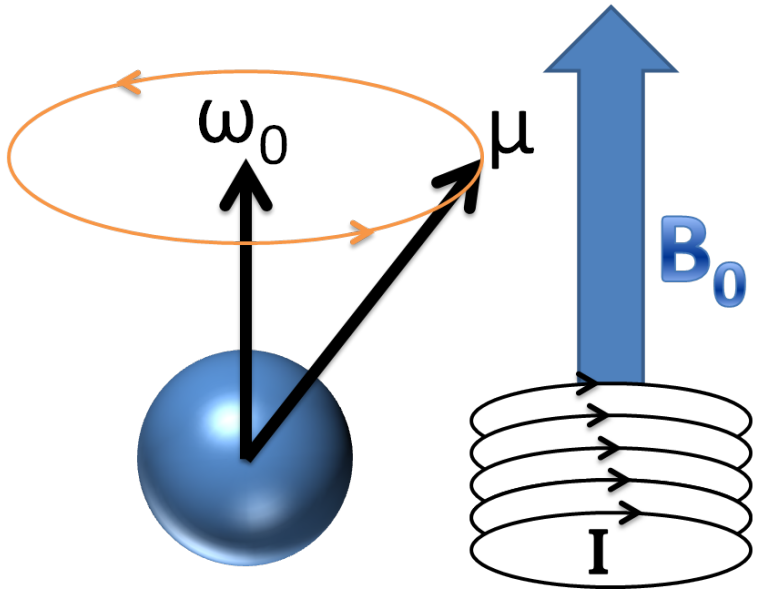
Co-magnetometer

- Located within the UCN cell at the center of the passive and active shields and the B_0 coil.
- Atomic species with spin-1/2 and a small neutron capture cross-section (Xe, Hg).



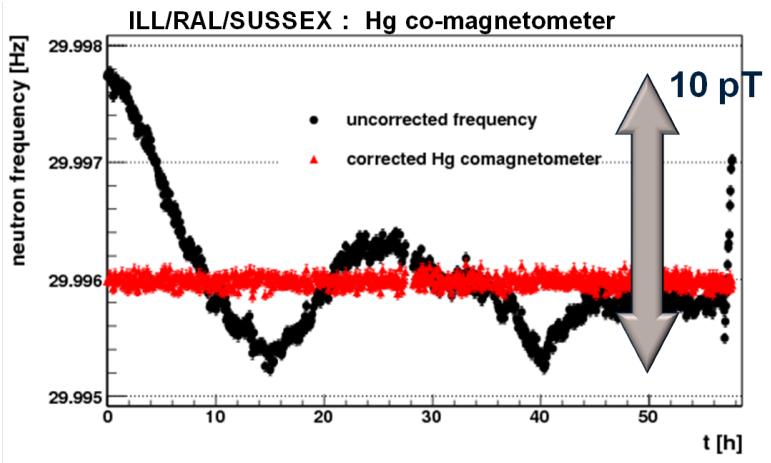
Co-magnetometer

- Located within the UCN cell at the center of the passive and active shields and the B_0 coil.
- Atomic species with spin-1/2 and a small neutron capture cross-section (Xe, Hg).
- Using nuclear magnetic resonance (NMR), a precise measure of the magnetic field within the UCN cell can be achieved.



Co-magnetometer

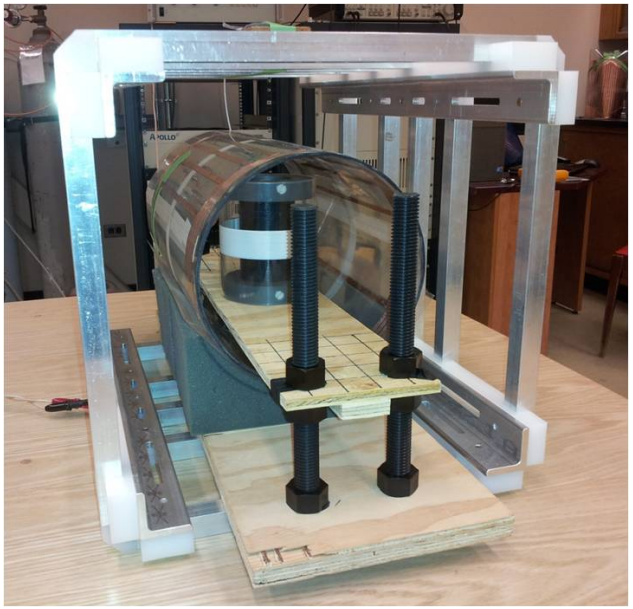
- Located within the UCN cell at the center of the passive and active shields and the B_0 coil.
- Atomic species with spin-1/2 and a small neutron capture cross-section (Xe, Hg).
- Using nuclear magnetic resonance (NMR), a precise measure of the magnetic field within the UCN cell can be achieved.
- Corrections to the nEDM measurement are performed using the co-magnetometer data.

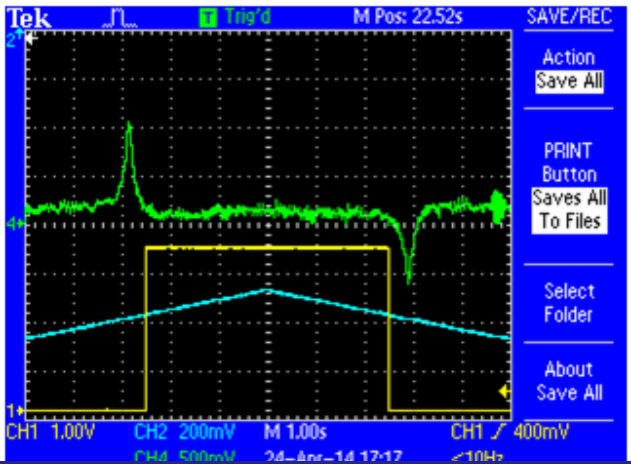


http://inspirehep.net/record/871294/plots

AFP-NMR at UW

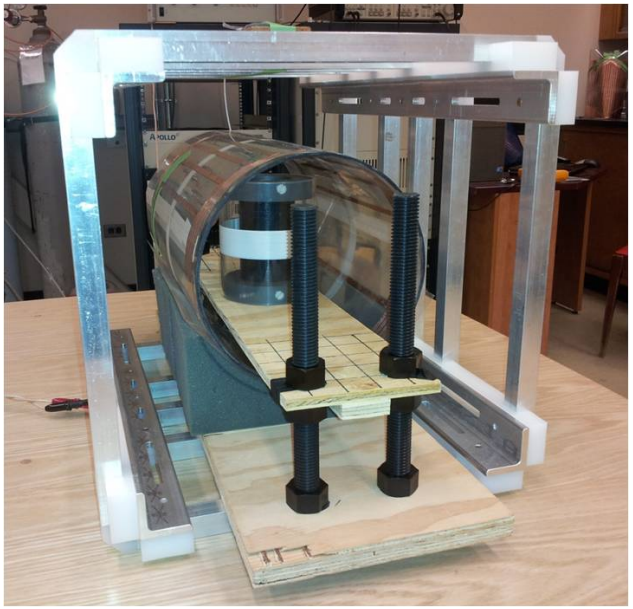
- The co-magnetometer gas is pre-polarized to achieve a strong NMR signal.

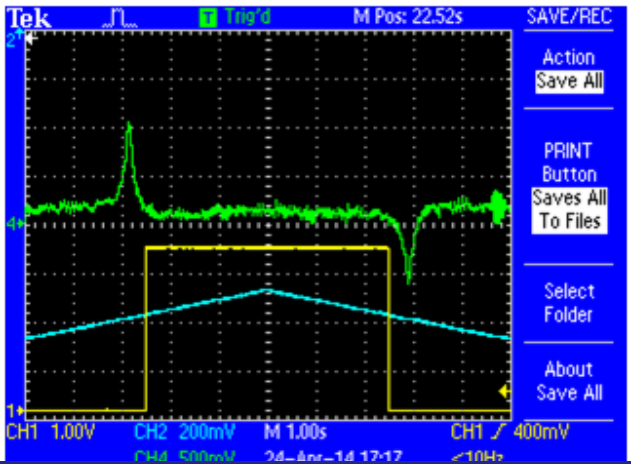




AFP-NMR at UW

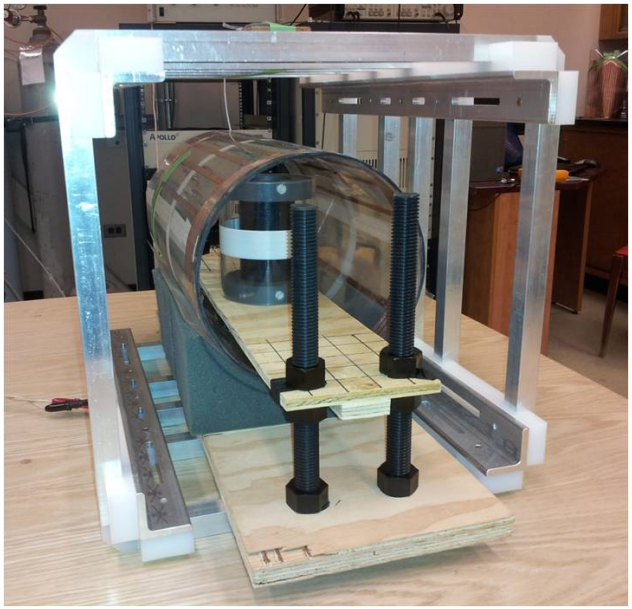
- The co-magnetometer gas is pre-polarized to achieve a strong NMR signal.
- Comparison of the NMR signal from a water sample, with the signal from a sample of polarized gas provides a measure of the polarization.

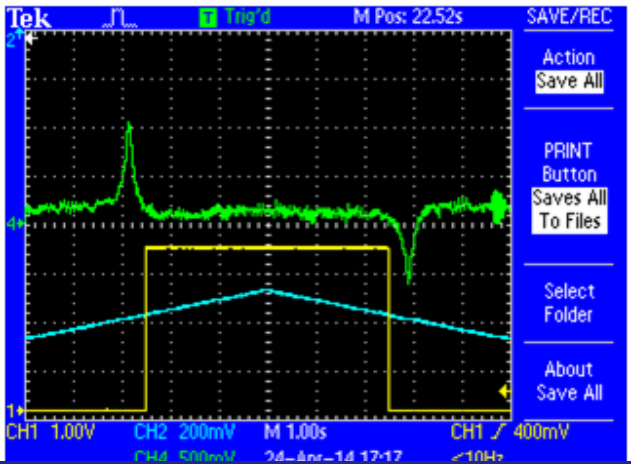




AFP-NMR at UW

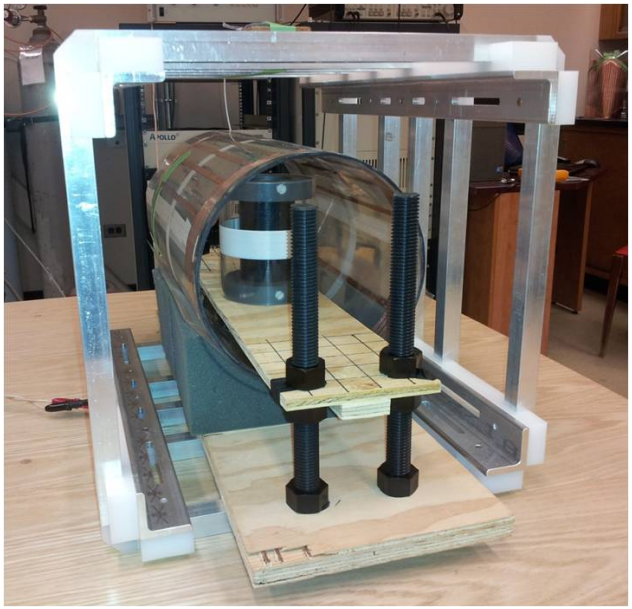
- The co-magnetometer gas is pre-polarized to achieve a strong NMR signal.
- Comparison of the NMR signal from a water sample, with the signal from a sample of polarized gas provides a measure of the polarization.
- Cell coatings can be tested for the ability to preserve polarization in the gas.

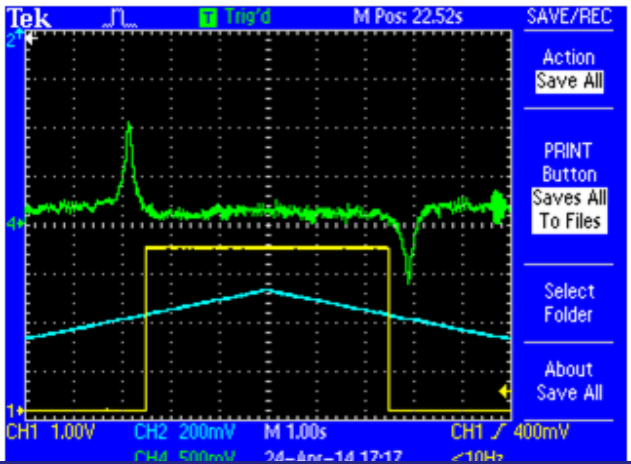




AFP-NMR at UW

- The co-magnetometer gas is pre-polarized to achieve a strong NMR signal.
- Comparison of the NMR signal from a water sample, with the signal from a sample of polarized gas provides a measure of the polarization.
- Cell coatings can be tested for the ability to preserve polarization in the gas.
- Studies of AFP-NMR are being performed at UWinnipeg to characterize the polarization system.





Conclusion

- We are working on many aspects of magnetic shielding and field stability at the University of Winnipeg.

Conclusion

- We are working on many aspects of magnetic shielding and field stability at the University of Winnipeg.
- With more refinement of our apparatus and techniques we are confident that we can meet the magnetic field requirements for the nEDM experiment at TRIUMF.

Conclusion

- We are working on many aspects of magnetic shielding and field stability at the University of Winnipeg.
- With more refinement of our apparatus and techniques we are confident that we can meet the magnetic field requirements for the nEDM experiment at TRIUMF.

Thank you for listening.