TUCAN

Adiabatic transport of polarized ultracold neutrons

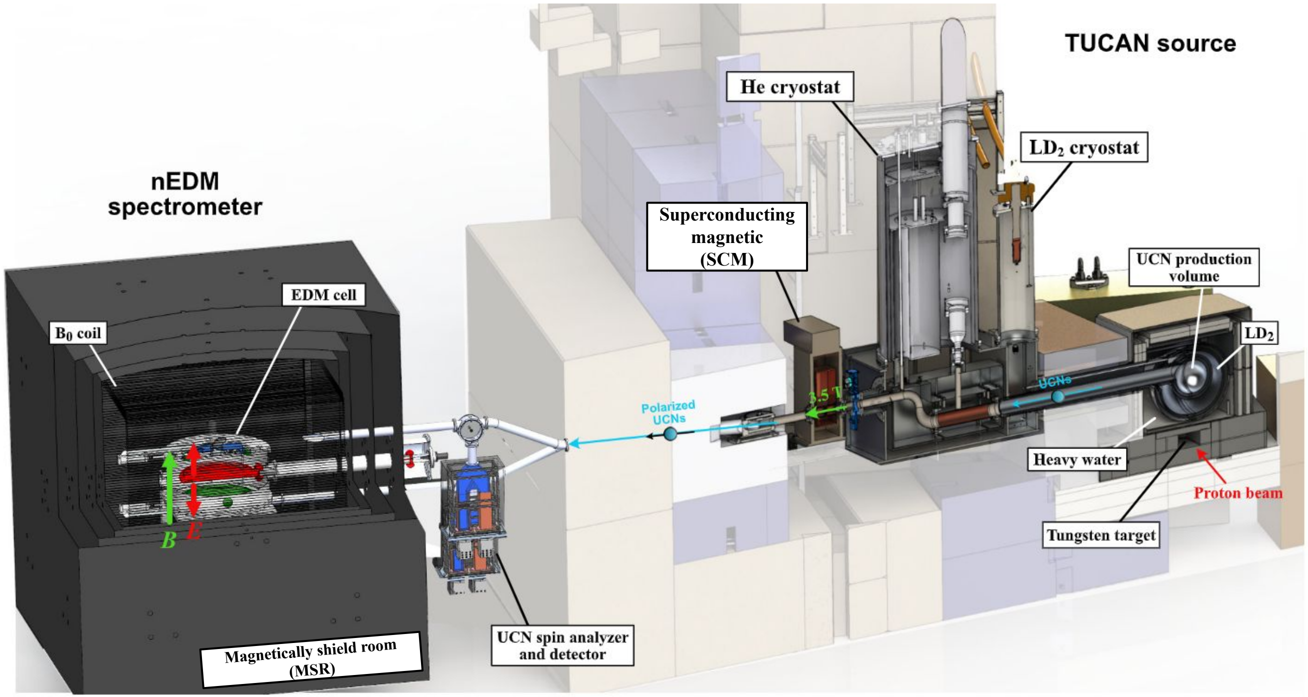
Emma Klemets (she/her)

Supervisor: Beatrice Franke

MSc student at UBC & TRIUMF

The TUCAN EDM experiment

- Looking for the neutron electric dipole moment (nEDM) at a projected sensitivity of 10^{-27} ecm
- Using polarized ultracold neutrons (UCNs)
- Requires very well understood and controllable magnetic & electric fields



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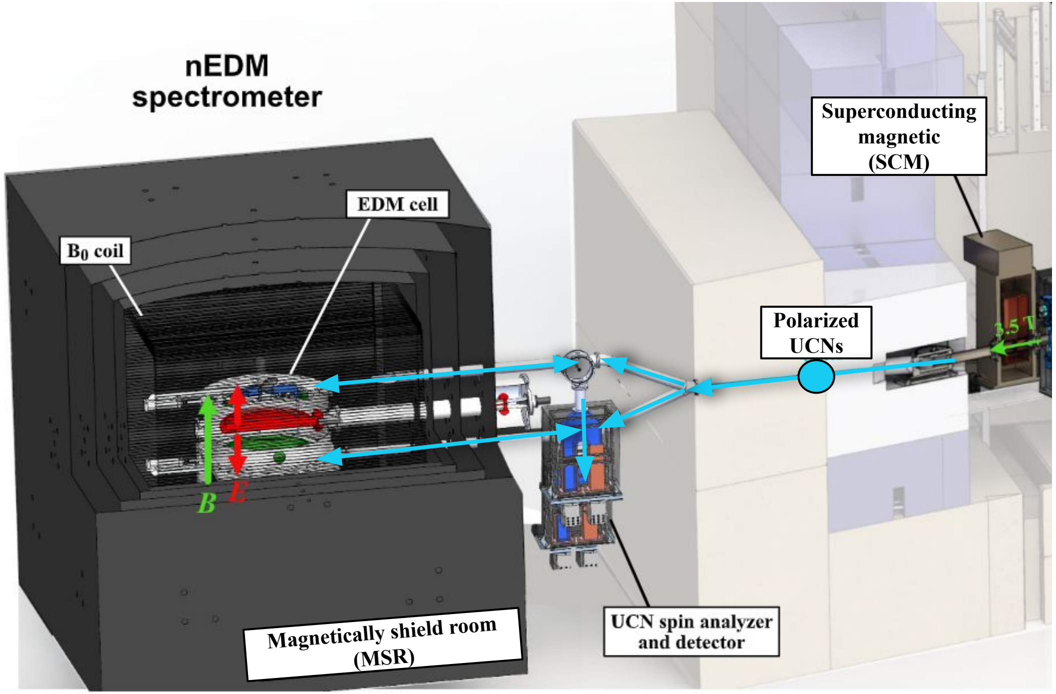


Adiabatic spin transport

We need our neutrons to not depolarize after the superconducting magnet.

Ensure adiabatic transport:

This is true when the **adiabatic parameter (*k*)** is large:

$$k = \frac{\omega_L}{\Omega} = \gamma_n \frac{B^2}{\frac{dB}{dt}}$$

Larmor precession frequency

Magnitude of magnetic field

Angular frequency of the changing B field

Gyromagnetic ratio of the neutron

Change of magnetic field in the neutron frame

This requires:

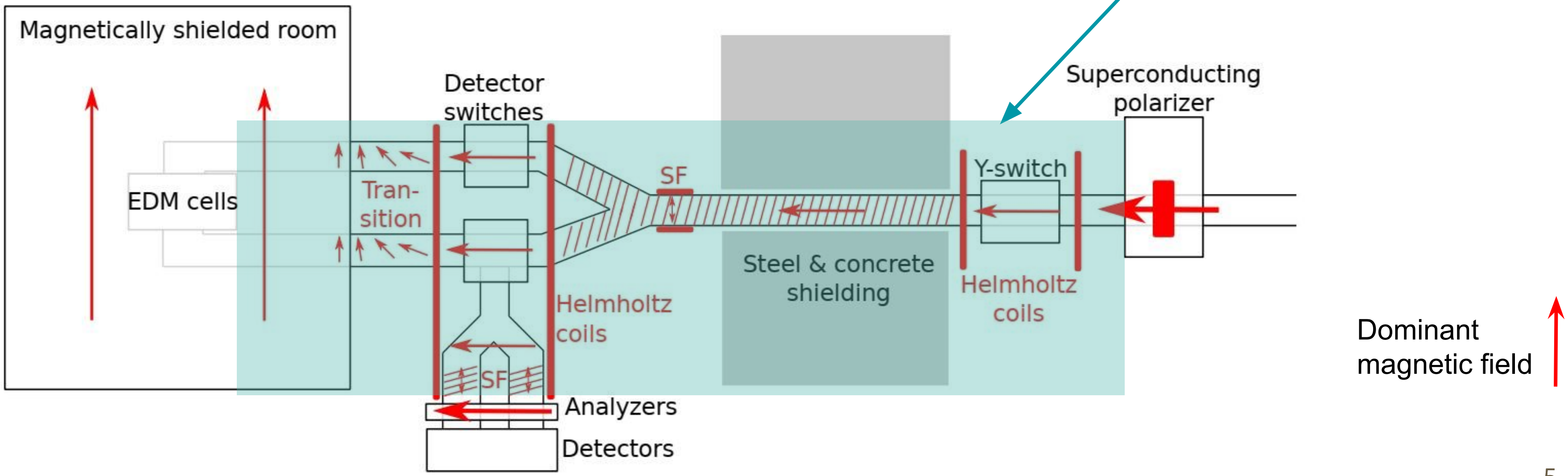
- No $|\vec{B}| = 0$ field transitions
- Slow $\vec{B}$ field changes in the guide regions

Neutron guiding fields

Control the magnetic field in the neutrons guides tubes, so they satisfy these two requirements.

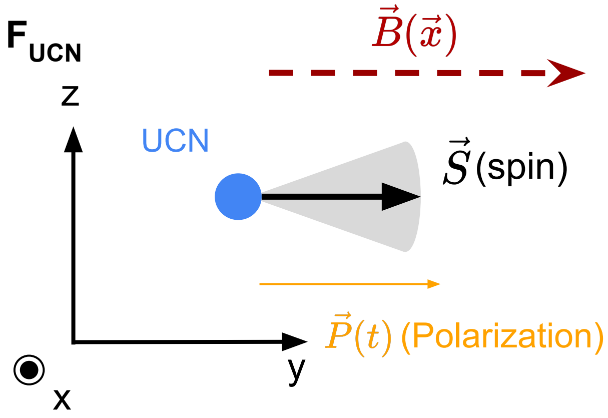
No $|\vec{B}| = 0$ Slow $\frac{d\vec{B}}{dt}$

This will be done by a series of coils placed around the guides.



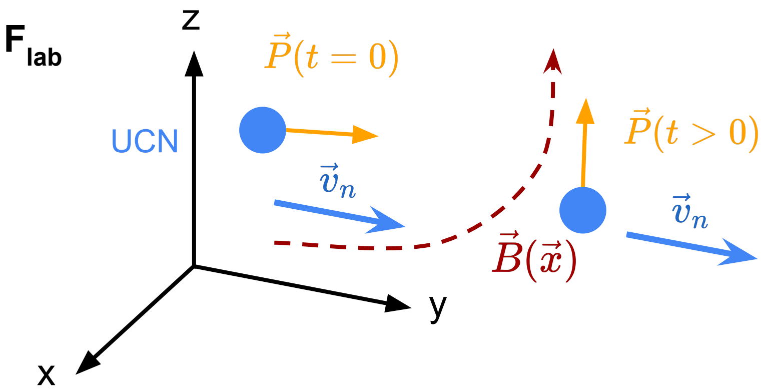
Spin in a magnetic field

Magnetically straight sections



Magnitude of $\vec{B}$ changes

Magnetic turn sections



Direction of $\vec{B}$ changes

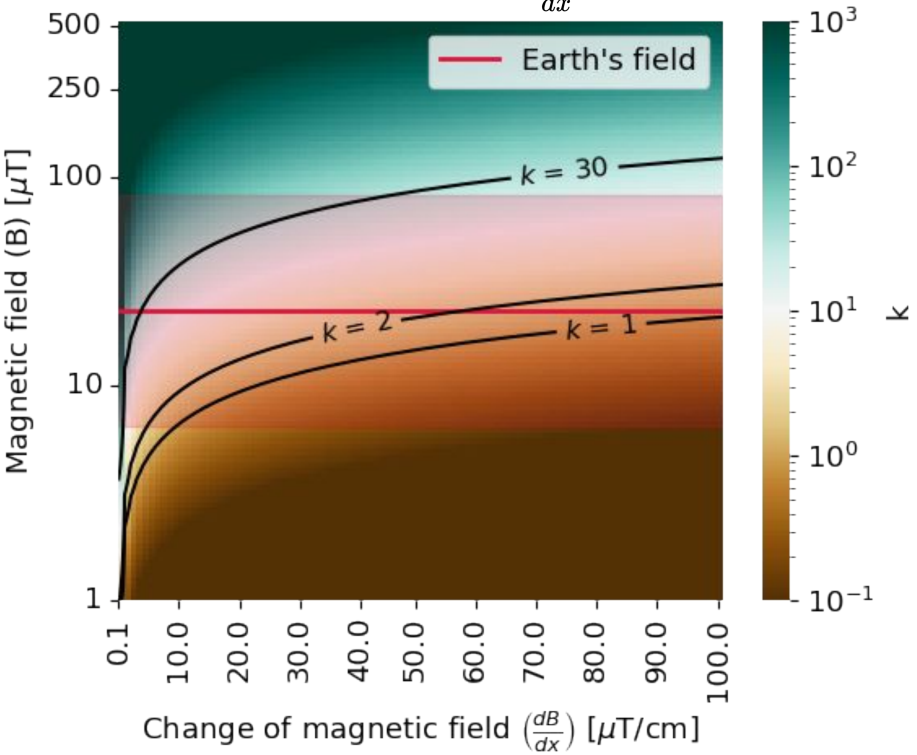
Magnets field requirements

No $|\vec{B}| = 0$ Slow $\frac{d\vec{B}}{dt}$

$v_n = 8$ m/s

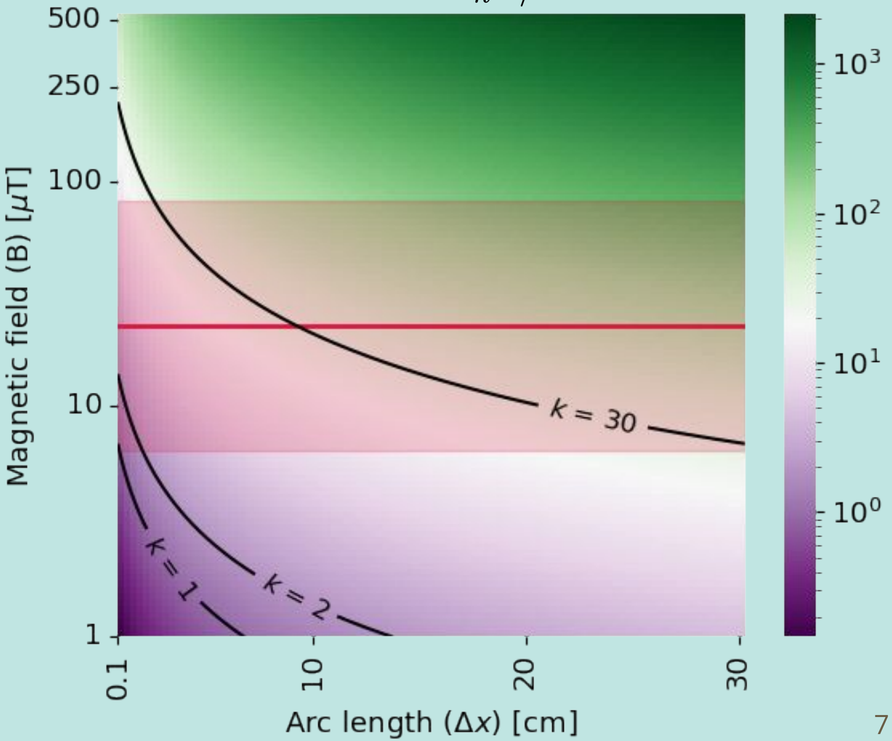
The change of B along the neutrons path

$$k = \gamma_n \frac{B^2}{v_n \frac{dB}{dx}}$$



The distance it takes to perform a $\pi/2$ rotation

$$k = \frac{\gamma_n B \Delta x}{v_n \pi/2}$$



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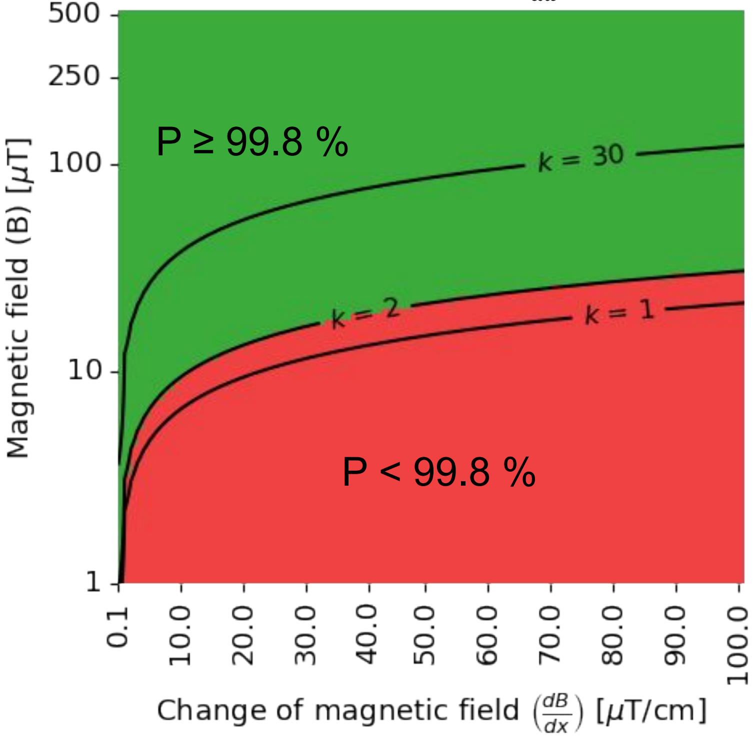

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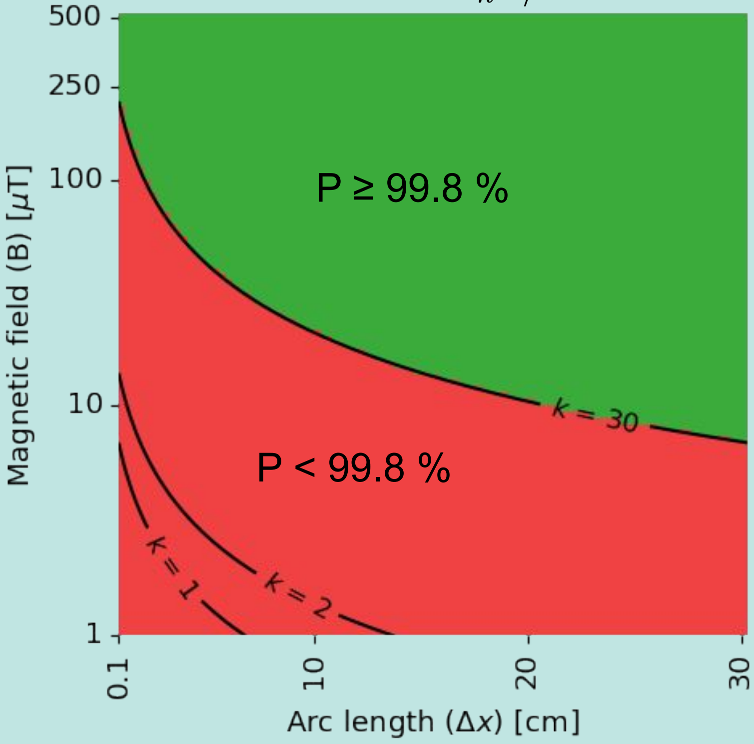
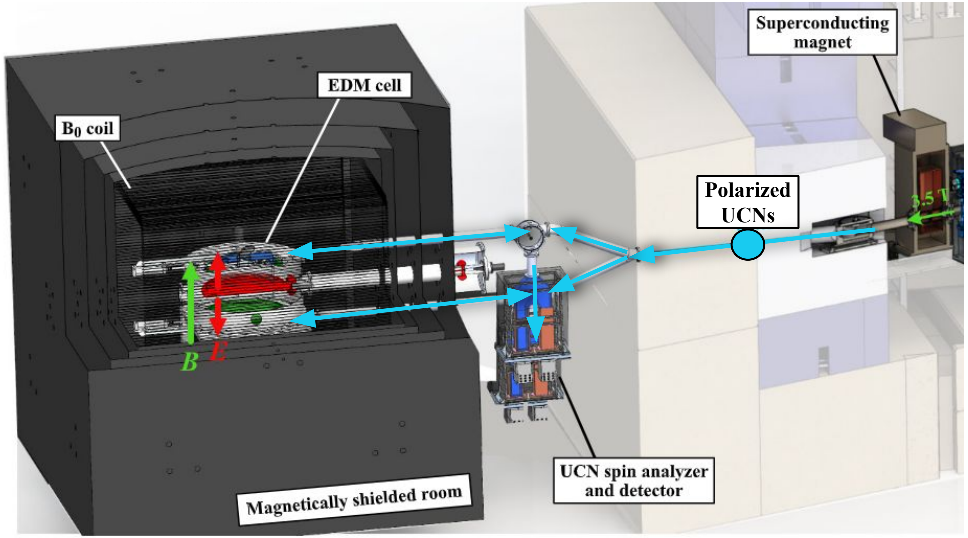
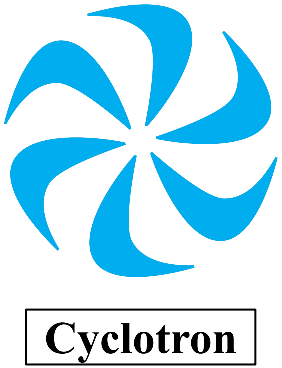


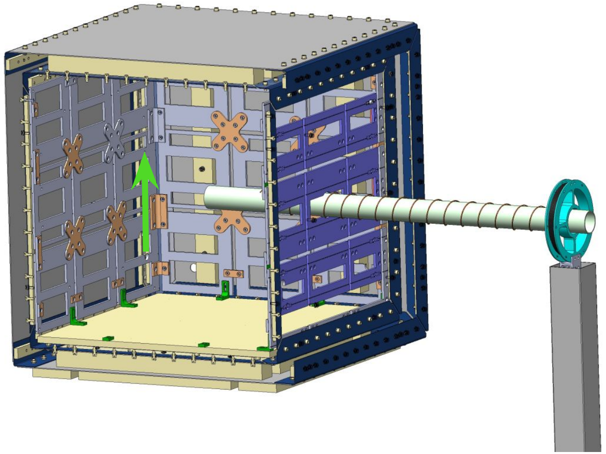
Completed EDM experiment setup

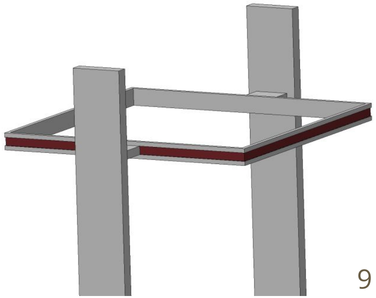




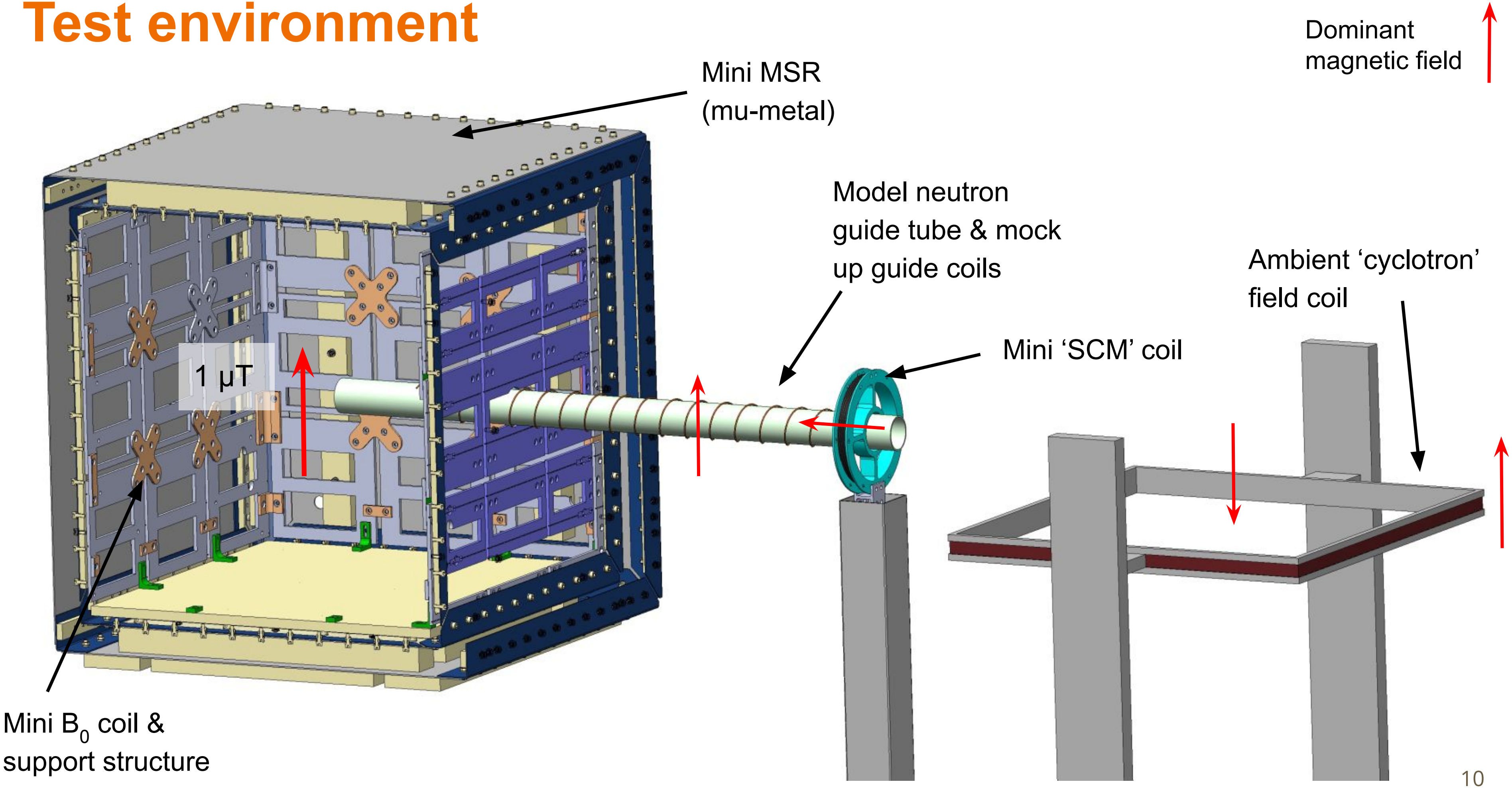
Test environment setup

Goal: measure transitions of major magnetic components to calculate *k*



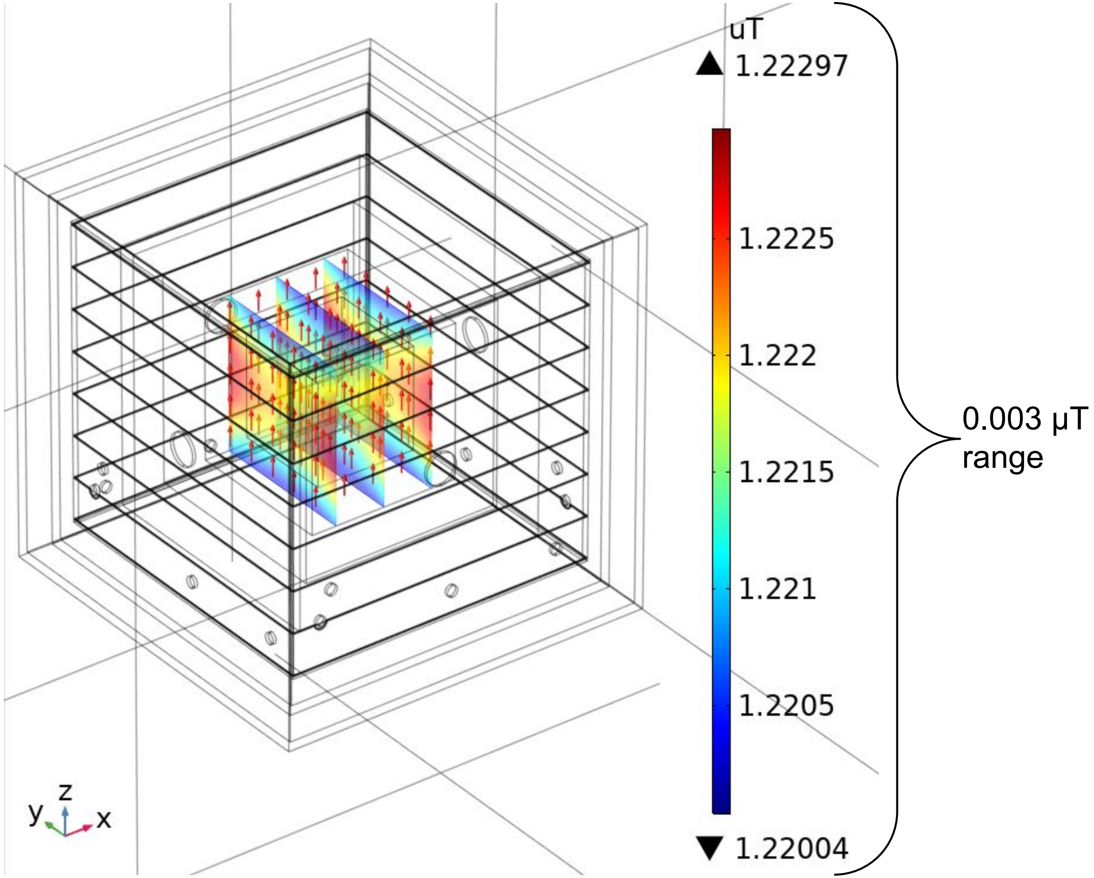


Test environment

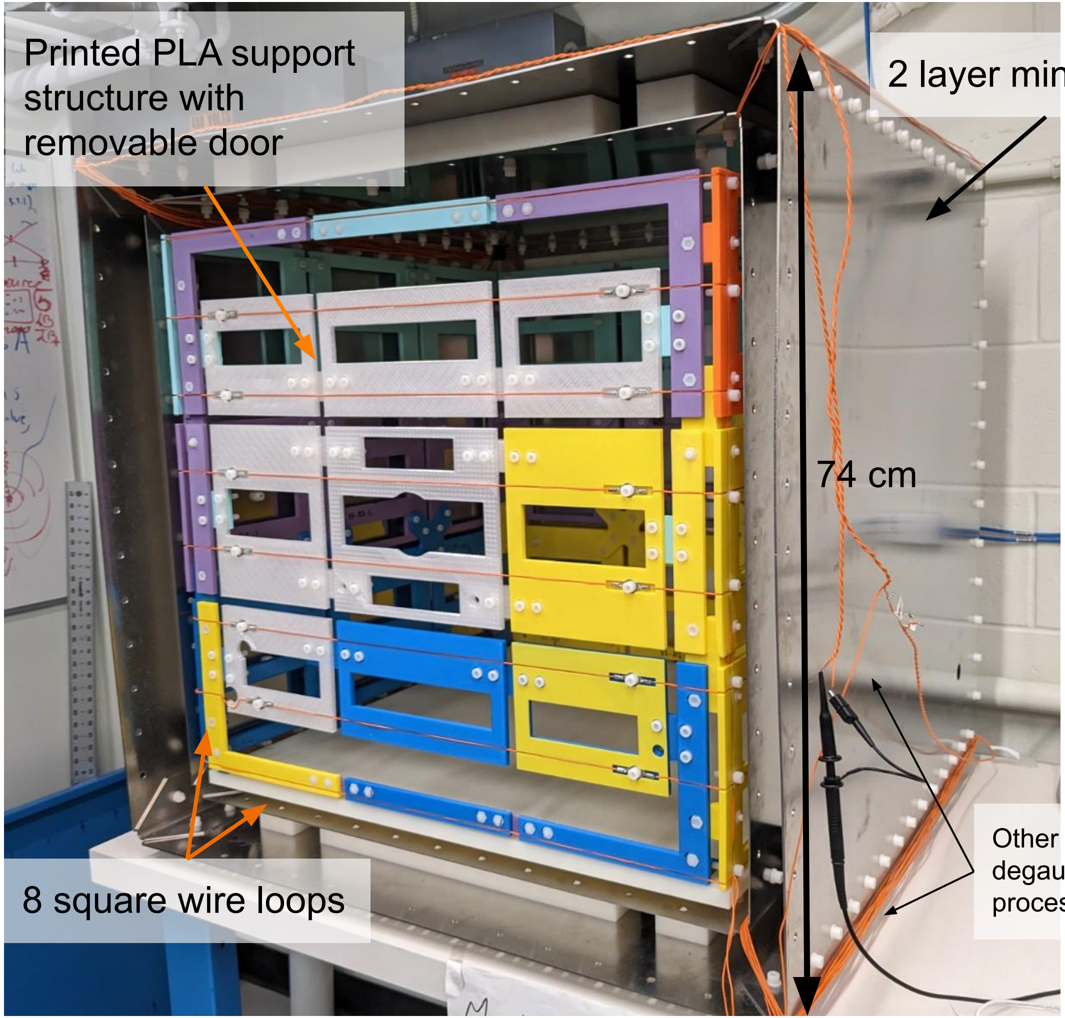


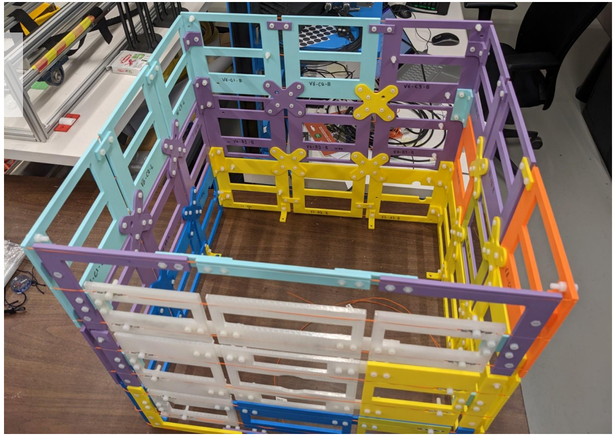
The mini B_0 coil

- Series of square loop coils
- In the region of interest of ~30 cm^3 the goal is:
  - 1 μT vertical field, within 10%
  - ~1 nT transverse fields

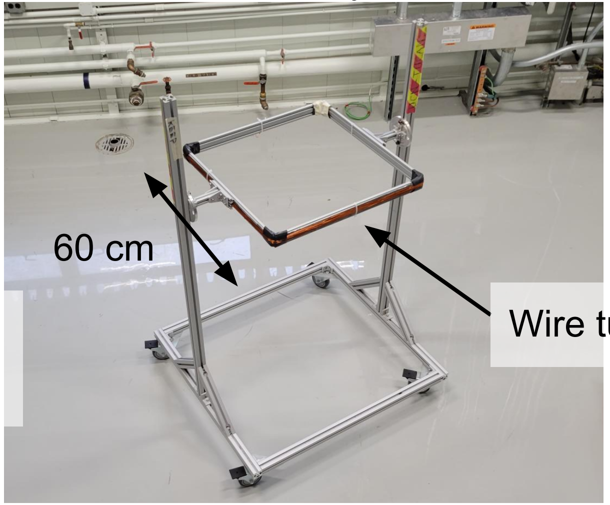


COMSOL simulation of 8 loop coil inside two layers of mu-metal, shown is the B_z field component





Coil to model the cyclotron field



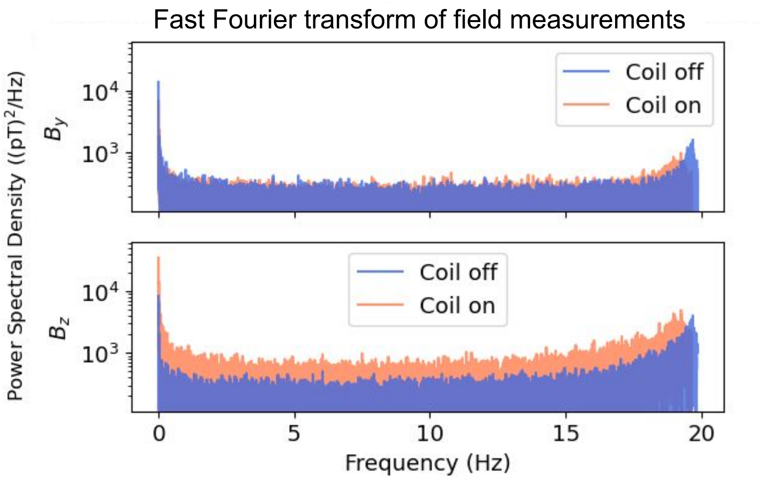
Testing results of Mini B_0 coil

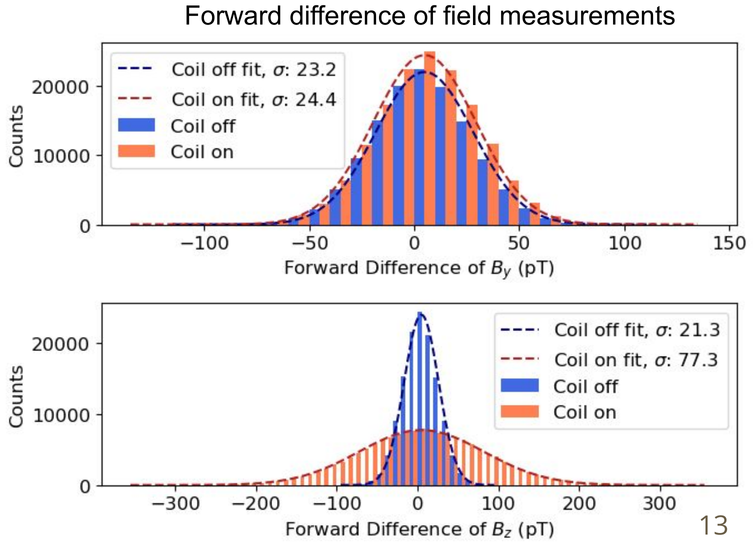
Results for 4 hour data runs:

	Mean (μT)	Standard deviation (μT)
Coil Off		
B_{vertical}	0.1793	0.0001
$B_{\text{transverse}}$	0.2435	0.0002
Coil On		
B_{vertical}	1.3802	0.0003
$B_{\text{transverse}}$	0.2492	0.0002

6 nT increase in transverse field
→ goal was ~ 1 nT

0.02 % stability for vertical field while coil is on
→ much better than 10%

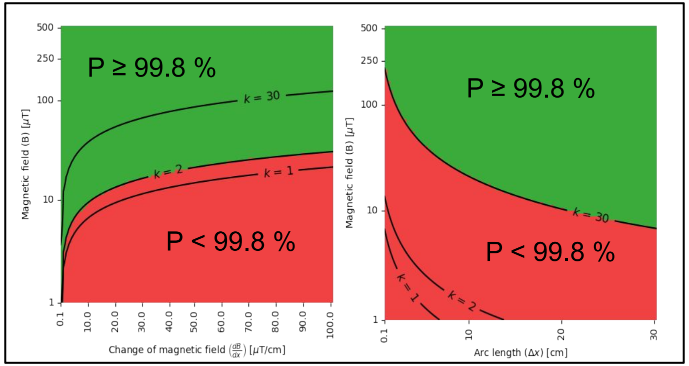


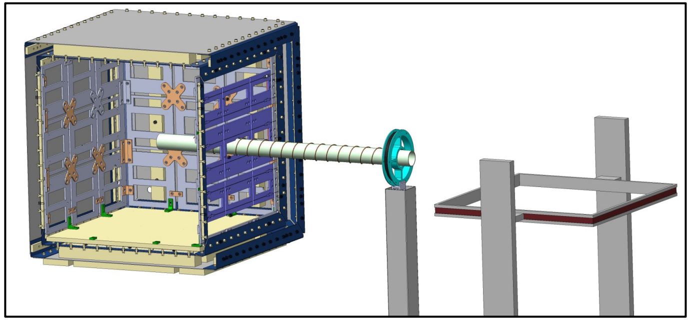


Conclusions

- Excluded region of magnetic field for fulfilling adiabatic transport requirements

- Design and simulation of magnetic test environment





TUCAN
TRIUMF Ultra Cold Advanced Neutron source

Thank you

TRIUMF

NSERC CRSNG

CINP ICPN
Canadian Institute of Nuclear Physics
Institut canadien de physique nucléaire

Extra slides

k reflects how well the UCN's polarization vectors can follow the B field

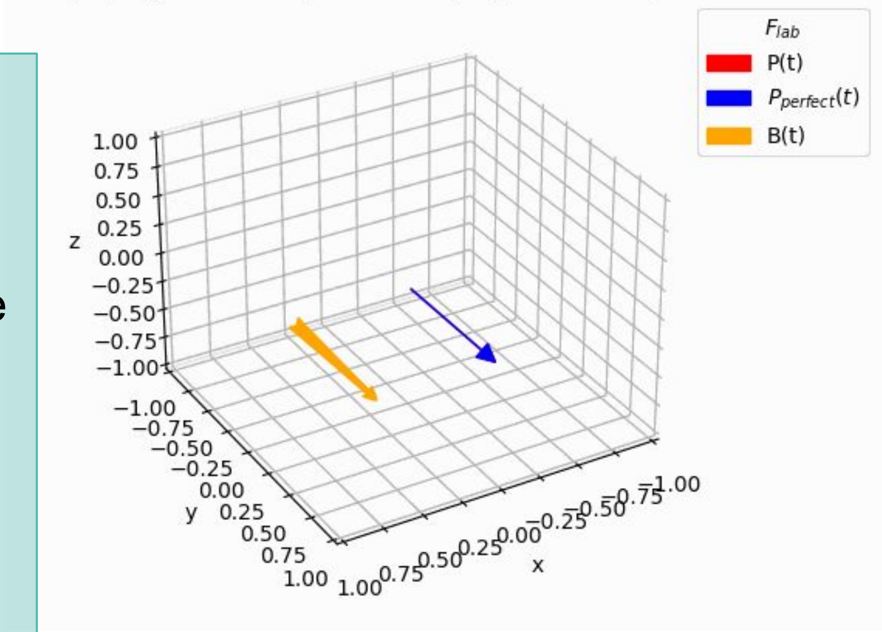
Adiabatic: $k \gg 1$

Questions:

- How big is big enough for *k?*
- How to calculate *k* with useful, measurable parameters?

$$\boldsymbol{k} = \frac{\omega_L}{\Omega} = \gamma_n \frac{B^2}{\frac{dB}{dt}} = \frac{\gamma_n B^3}{|\dot{\vec{B}} \times \vec{B}|}$$

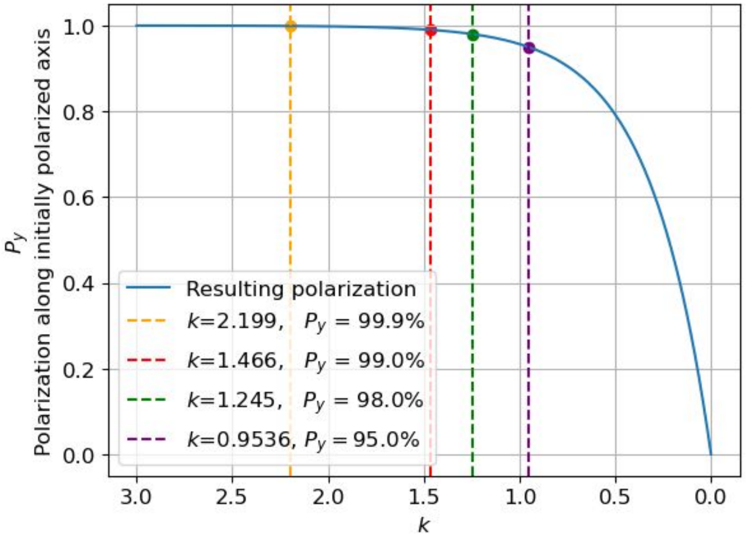
Example of spin precession in a constant, rotating B field



Minimum required k

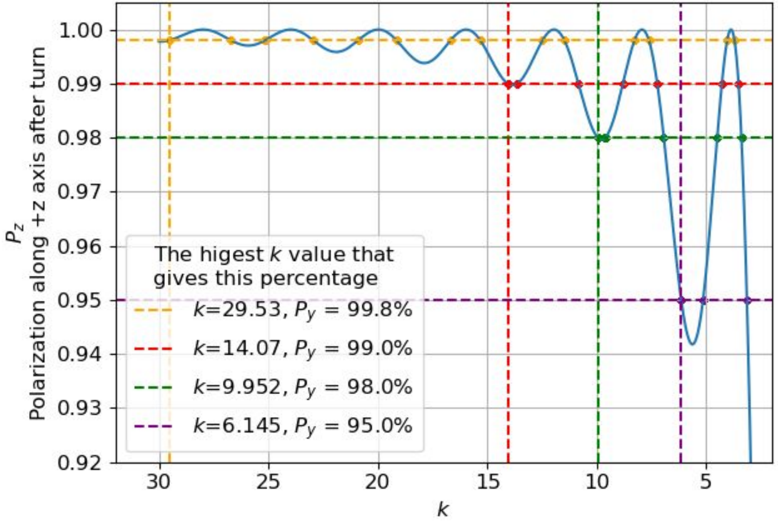
Magnetically straight sections

Exponential relation between the resulting polarization (P_y), along the same axis as the initial polarization, and *k*



Magnetic turn sections

The final polarization along the new axis after a turn is made in the lab frame. This leads to a more complicated relation to *k* and the angle of the turn to be made (θ)

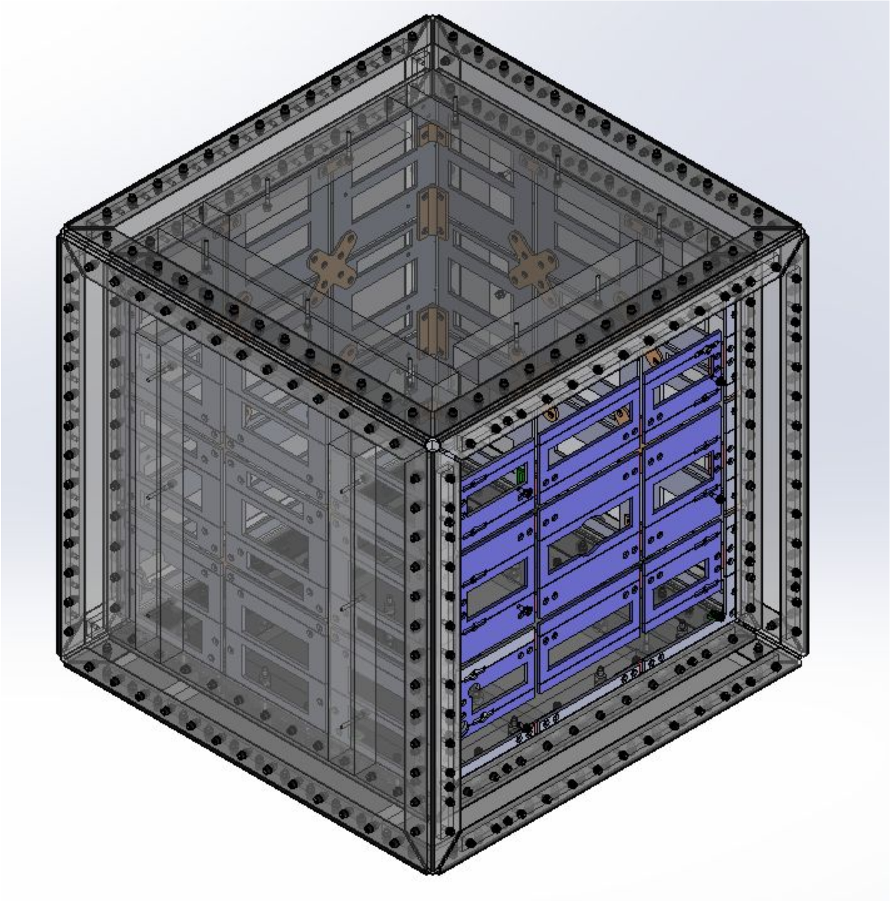


Requirement for final polarization of greater than 99.8%

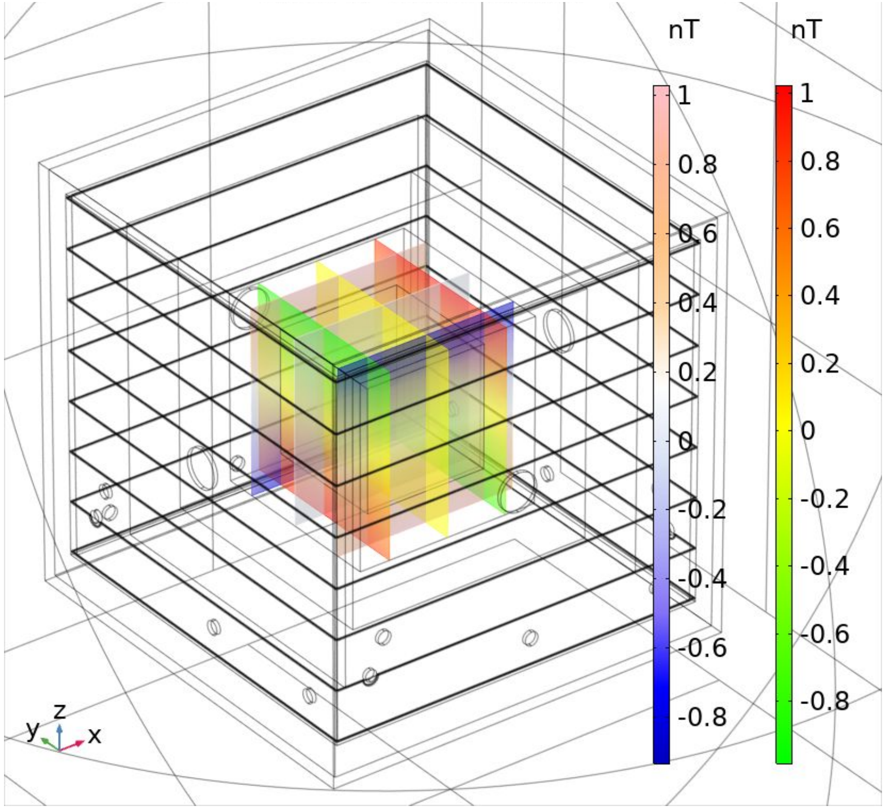
$$k > 2$$

$$k > 30$$

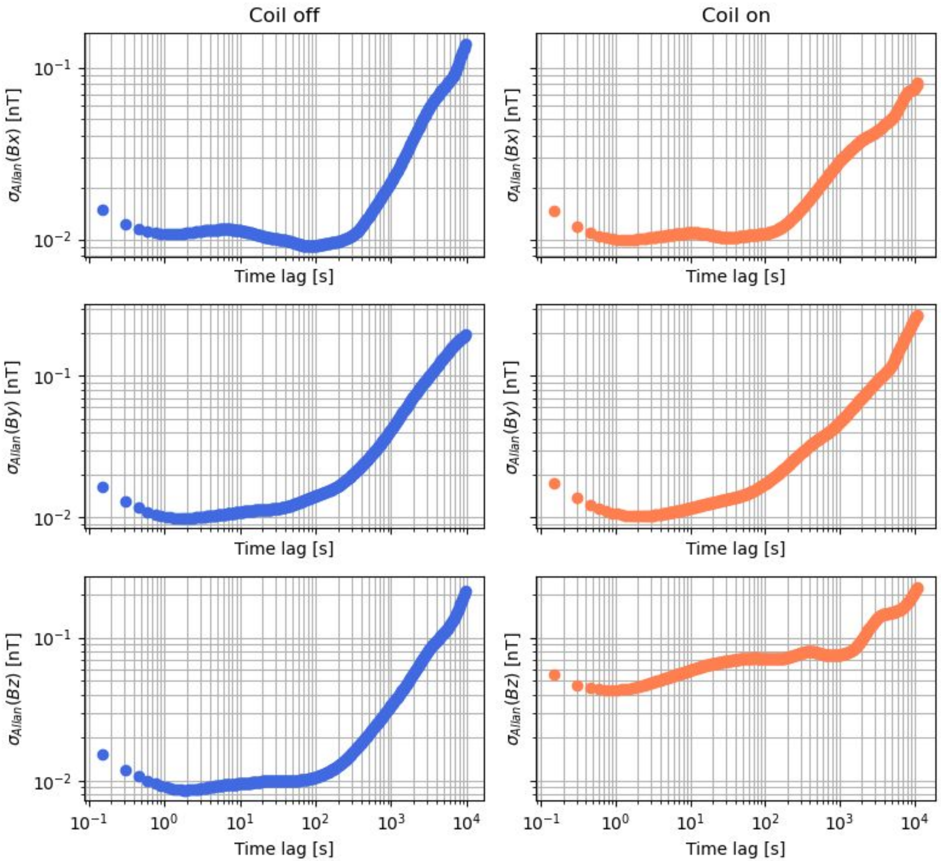
Extra Mini B_0 coil photos



Slices of the two transverse field components from the B_0 COMSOL simulation



Allan deviations for overnight data runs



Forward differences for high frequency data runs