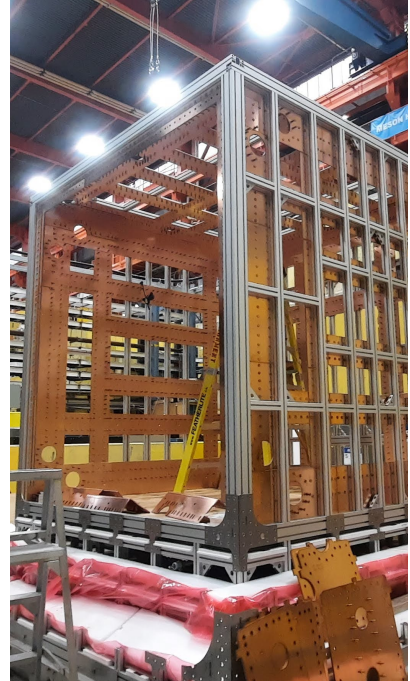
TRIUMF

An Introduction to the TUCAN EDM Measurement

Dr. D. Fujimoto

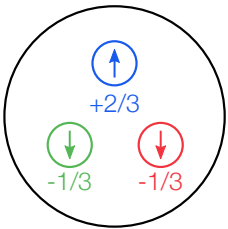
2023-02-17



TUCAN
TRIUMF Ultra Cold Advanced Neutron source

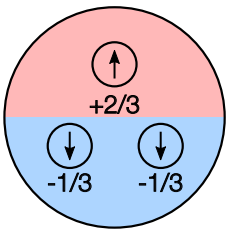
Discovery, accelerated

Neutron Electric Dipole Moment (nEDM)



Neutron

Neutron Electric Dipole Moment (nEDM)



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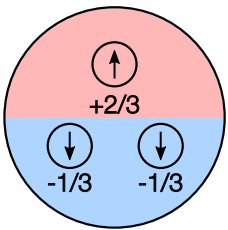

Neutron

$$d_{\mathrm{n}} \leq 10^{-27}\,\mathrm{e}\cdot\mathrm{cm}$$

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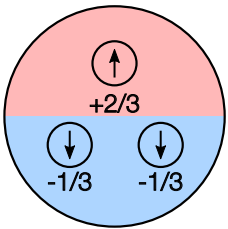


Neutron

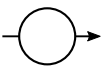
$$d_{\mathrm{n}} \leq 10^{-27}\,\mathrm{e}\cdot\mathrm{cm}$$

Matter/antimatter asymmetry

Why do we have stuff?

Image: www.nasa.gov

How to measure the nEDM?



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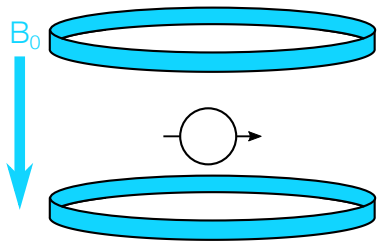

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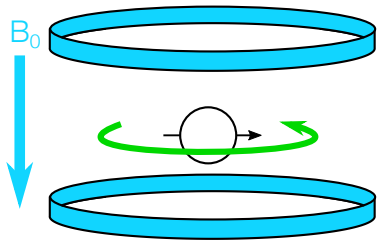

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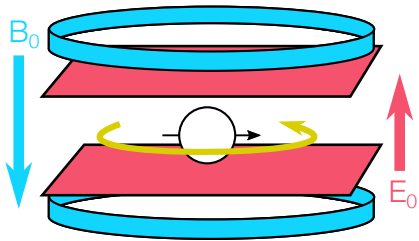

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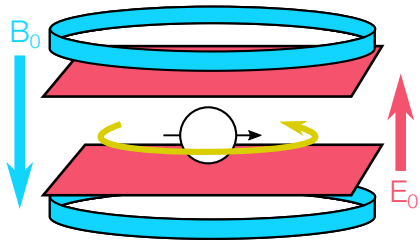
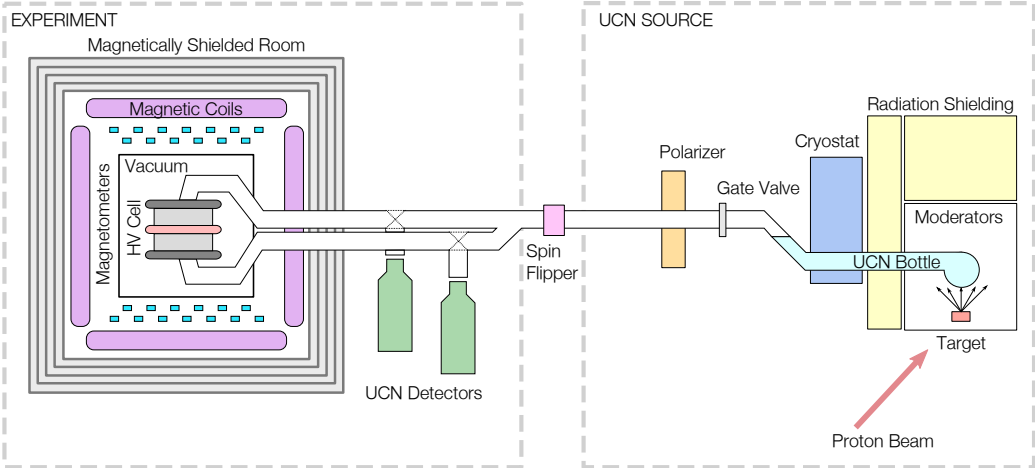


$$d_{\mathrm{n}} = \frac{\pi\hbar}{2E_0}(\nu^{\uparrow\downarrow} - \nu^{\uparrow\uparrow})$$

The TUCAN nEDM experiment



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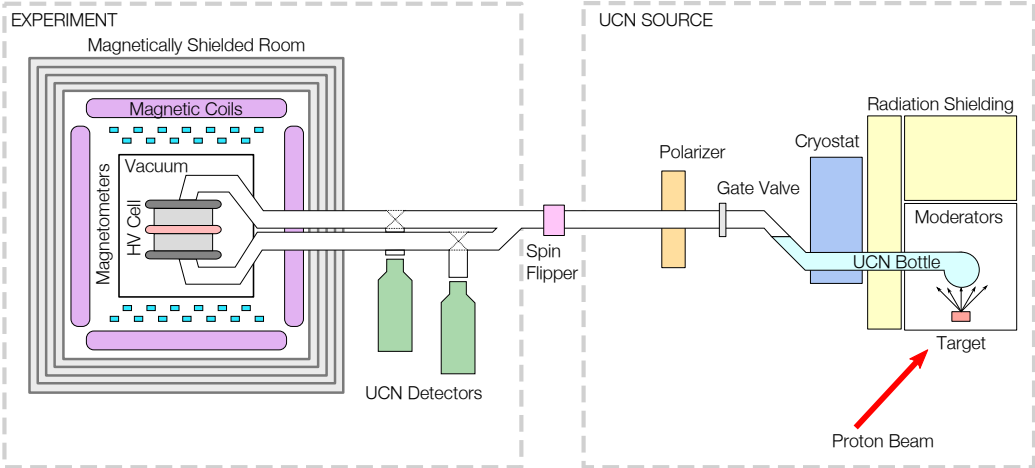

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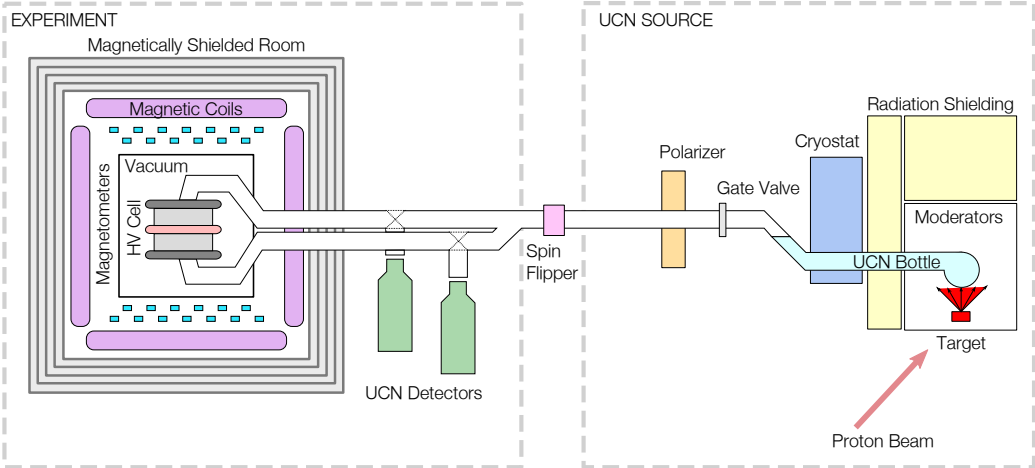

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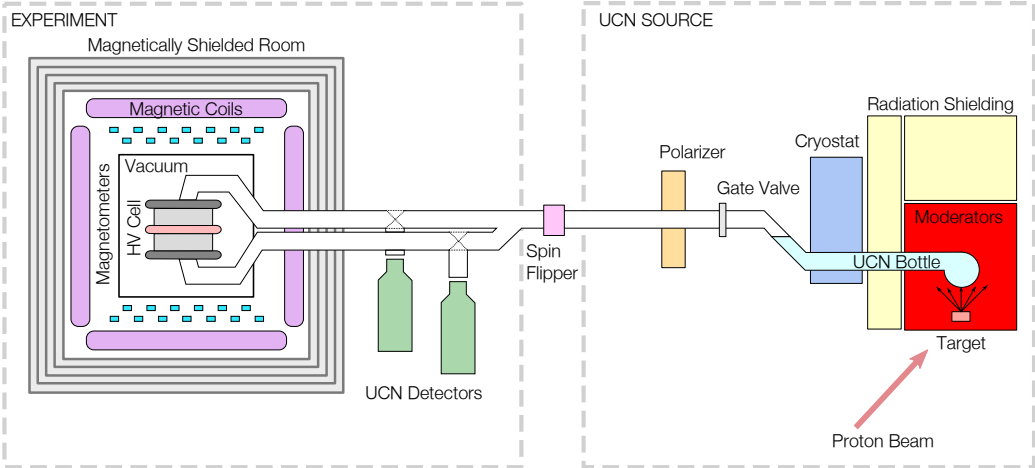

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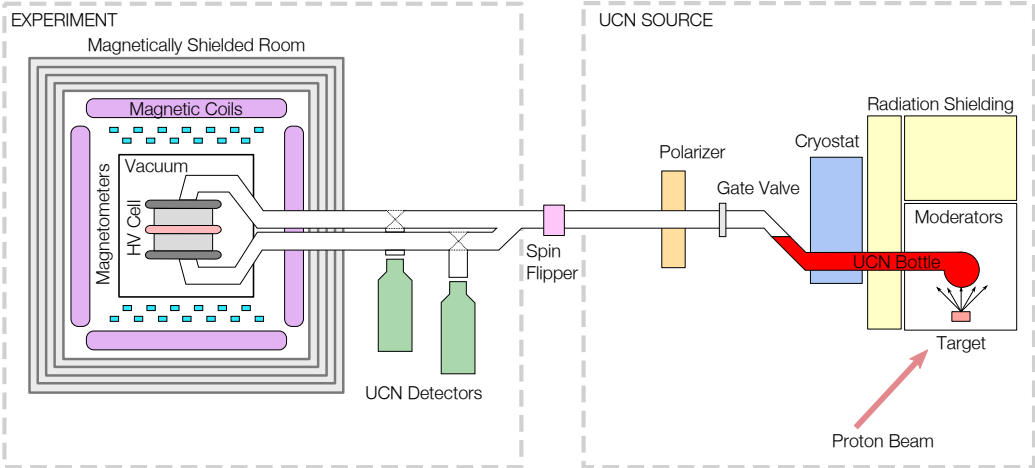

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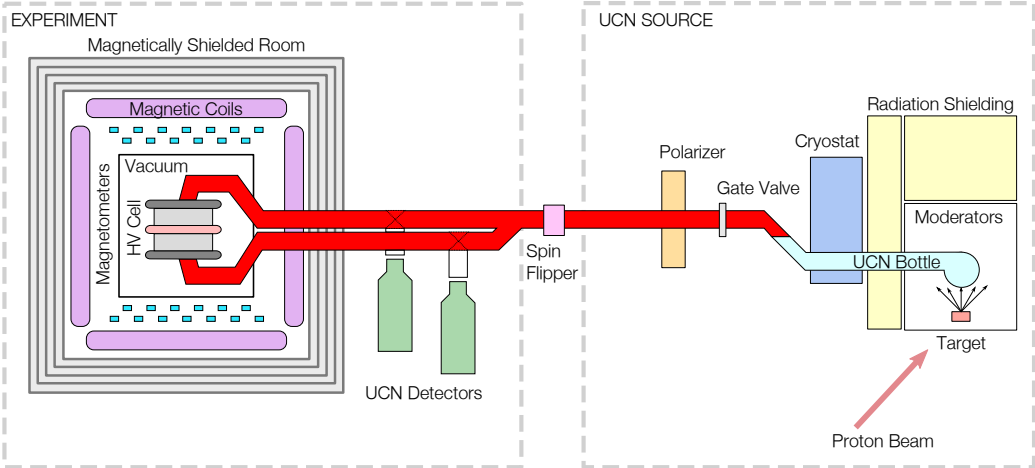

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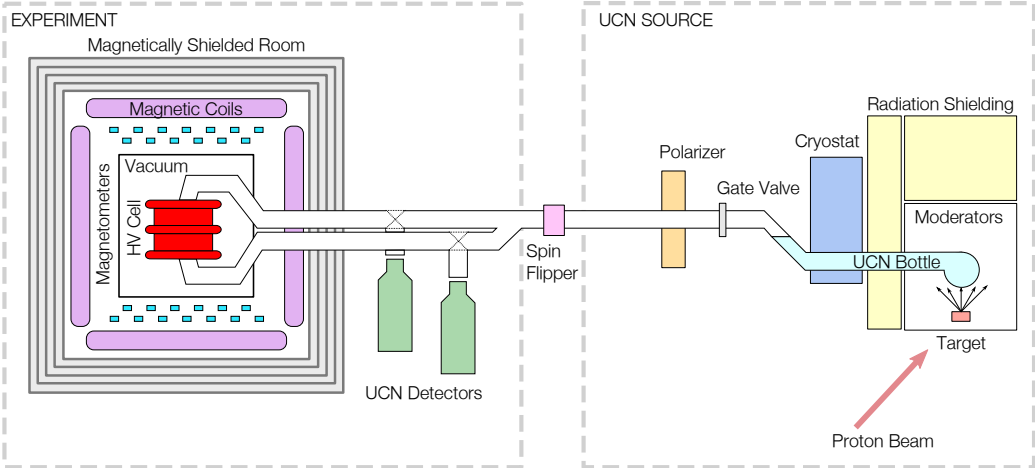

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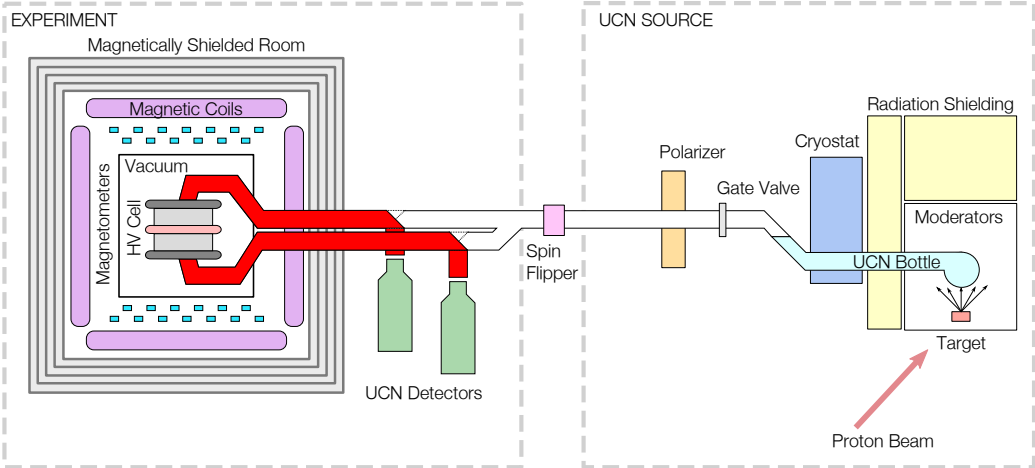

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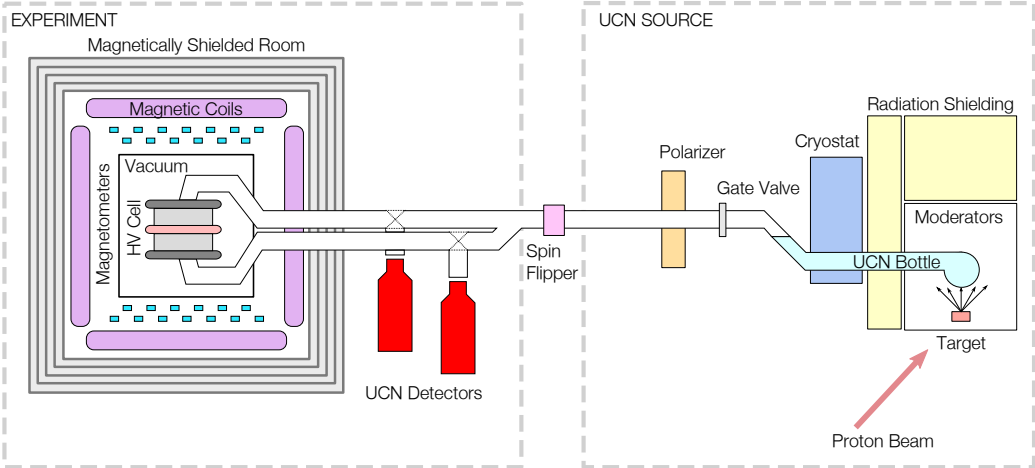
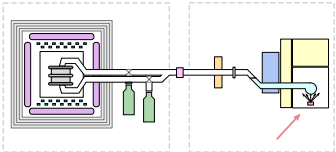


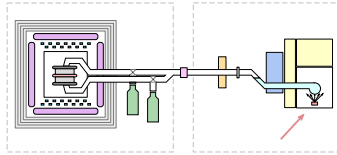
Measurement Challenges



Three big categories:

- → **Achieving high statistics**
  (lots of neutrons)
- → **Creating, controlling, and detecting polarization**
  (maintain spin alignment)
- → **Minimizing systematics**
  (pesky experimental realities)

Measurement Challenges



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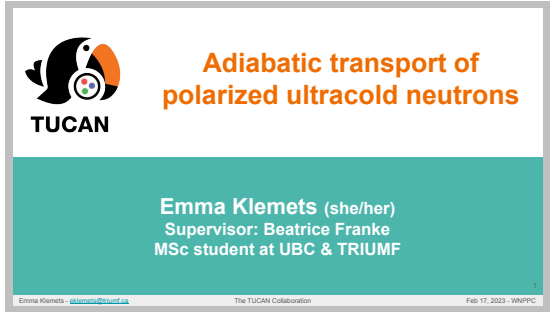
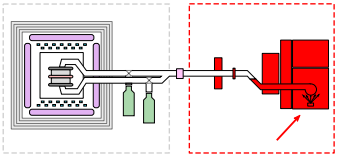
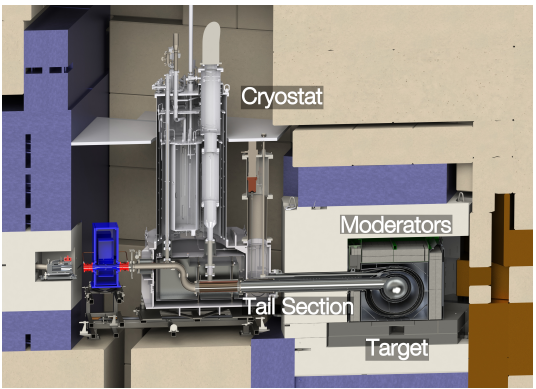


Achieving high statistics



UCN source components:

- → Proton beamline
- → Target
- → Neutron moderators and reflectors
- → Liquid He tail section
- → LHe and LD_2 cryostats



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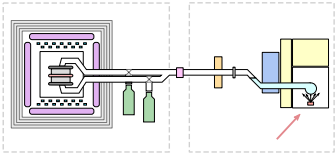
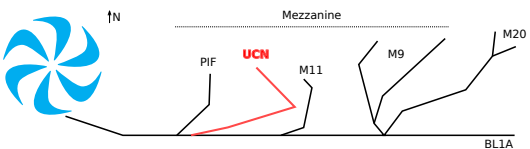


Beamline and target

- → Beamline run at $1\,\mu A$ (2017-2019)
- → 2023: preparing for $40\,\mu A$ (expected: 10^7 UCN/s)



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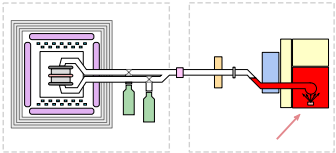
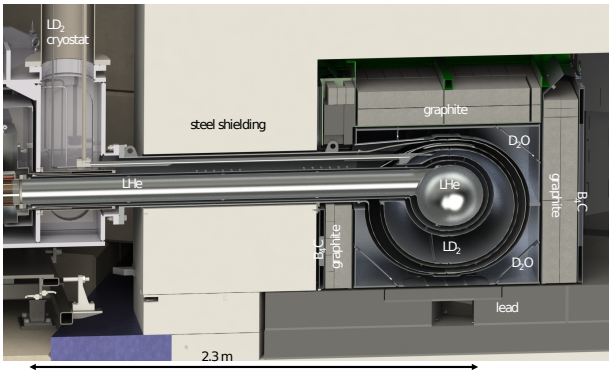


Tail section and moderators



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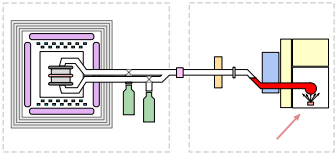
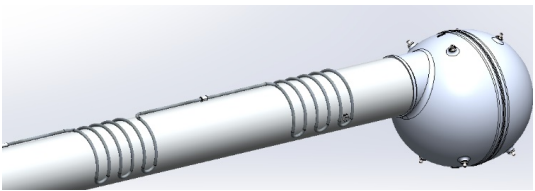


Tail section and moderators

- → Bulb: Innermost layer completed and leak-checked
- → Storage capabilities validated with UCN at LANL



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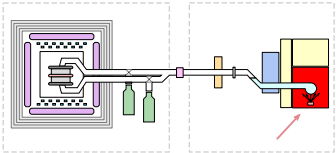
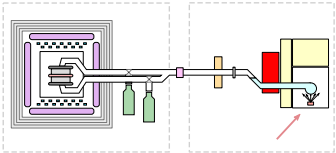


Tail section and moderators

- → Bulb: Innermost layer completed and leak-checked
- → Storage capabilities validated with UCN at LANL
- → Graphite carrier constructed and filled

Achieving high statistics



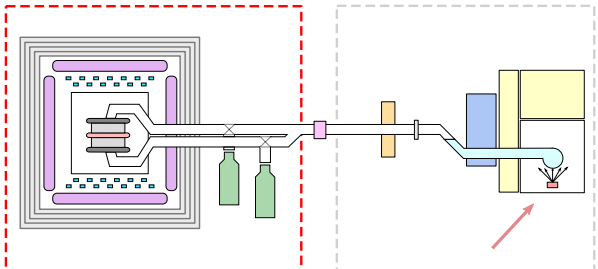
Cryostat

- → Cool LHe to $1.15\,\mathrm{K}$
- → Build completed and leak-checked
- → Lots of infrastructure installed (He recovery, cryo pumps, etc.)
- → 2023: installation and testing

Eliminating systematic errors

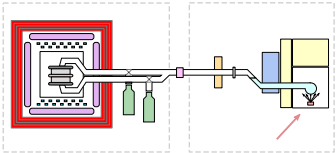
Arise primarily due to imperfect magnetic fields

- → **Field stability**
  - → Magnetically shielded room
  - → Atomic comagnetometer
- → **Field homogeneity**
  - → B_0 coil
  - → Mapper robot
  - → Cs magnetometers



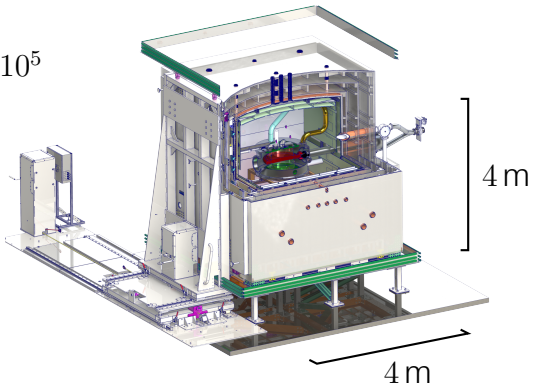
Eliminating systematic errors

Field stability



Magnetically shielded room

- → Reduce magnetic fields by a factor of 10^5
- → Keep noise <1 pT over ~ 100 s
- → Assembly complete this September



Eliminating systematic errors

Field stability

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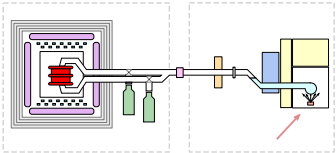
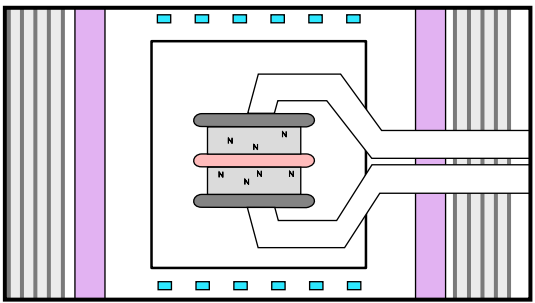


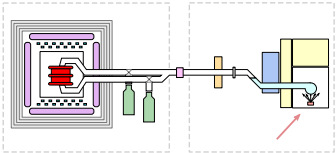
Atomic Comagnetometer

→ Measure magnetic field in neutron volume



Eliminating systematic errors

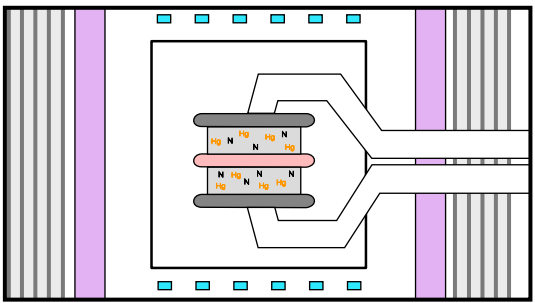
Field stability



Atomic Comagnetometer

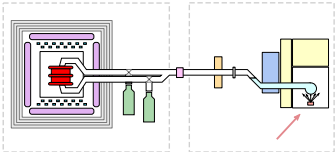
→ Measure magnetic field in neutron volume

→ Fill space with Hg gas



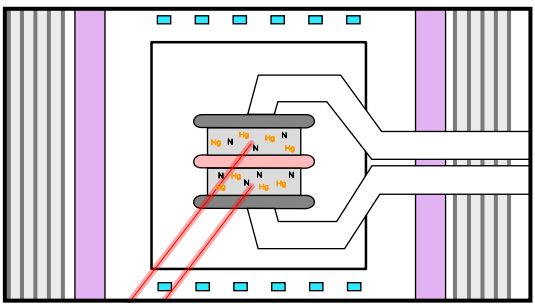
Eliminating systematic errors

Field stability



Atomic Comagnetometer

- → Measure magnetic field in neutron volume
- → Fill space with Hg gas
- → Optically measure precession frequency → $\langle B \rangle$



Eliminating systematic errors

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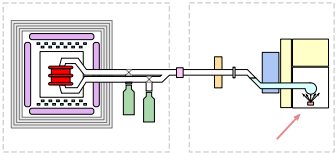
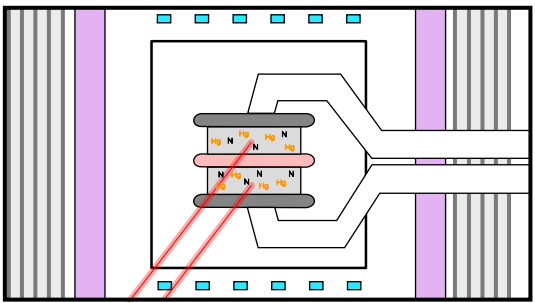


Atomic Comagnetometer

- → Measure magnetic field in neutron volume
- → Fill space with Hg gas
- → Optically measure precession frequency → $\langle B \rangle$
- → Prototype at UBC: work ongoing

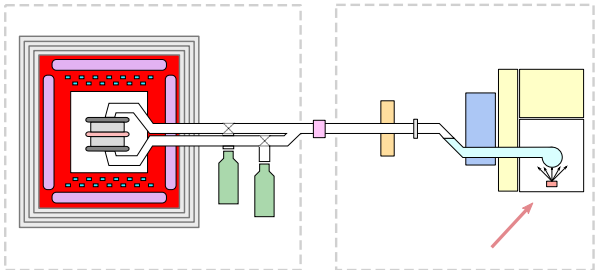


Eliminating systematic errors

Field homogeneity

Some highlights:

- $\rightarrow$ B_0 coil
- $\rightarrow$ Mapper robot
- $\rightarrow$ Cs magnetometers



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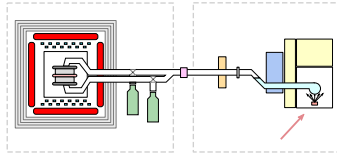
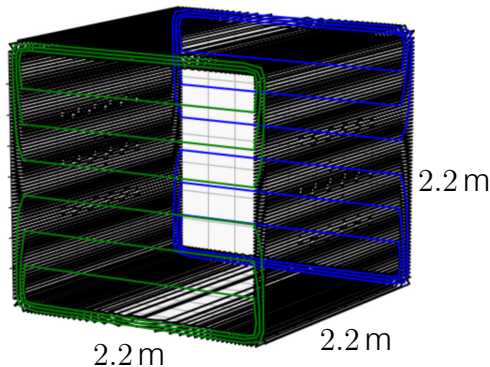


B_0 coil

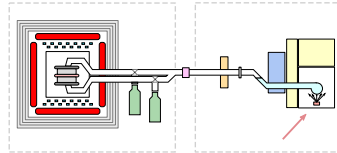
→ Produce a 1 µT magnetic field

→ Self-shielded design completed



Eliminating systematic errors

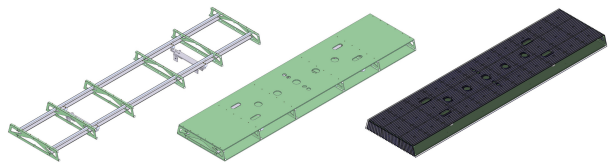
Field homogeneity



B_0 coil

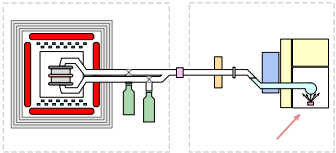
- → Produce a 1 µT magnetic field
- → Self-shielded design completed
- → Lightweight support frame design completed and tested for rigidity

G10 Frame Sandwich Skin Wire Guides



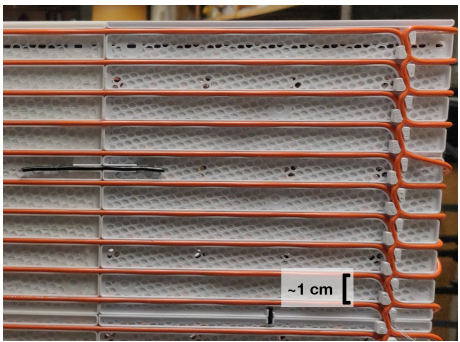
Eliminating systematic errors

Field homogeneity



B_0 coil

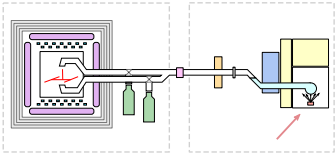
- → Produce a 1 μT magnetic field
- → Self-shielded design completed
- → Lightweight support frame design completed and tested for rigidity
- → Wire guides being 3D printed
- → Assembly completed end of summer



Wire guide panel

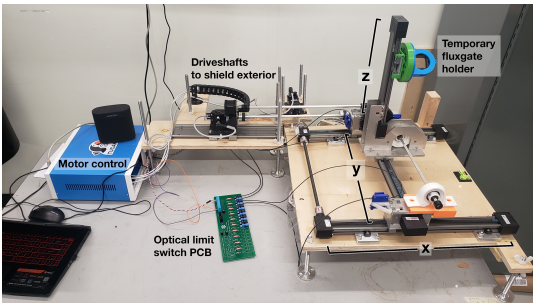
Eliminating systematic errors

Field homogeneity



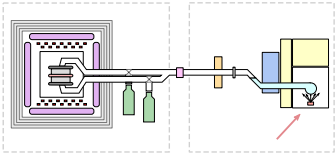
Mapper robot

- → Offline: Measure spatial grid with single magnetic sensor
- → Prototyped by UBC engineering physics students
- → Engineering ongoing, prototype operational end of summer



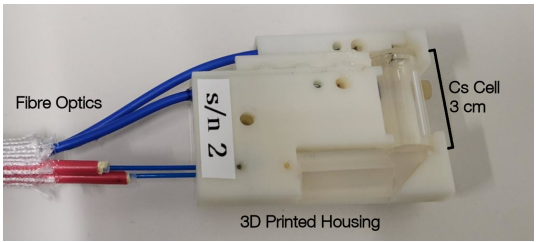
Eliminating systematic errors

Field homogeneity



Cs Magnetometers

- → Array of 20 probes to measure field gradients around HV cell
- → $\sigma_{\langle B \rangle} = 10\,\mathrm{fT}$, averaging over $100\,\mathrm{s}$
- → Manufacture, characterization ongoing
- → Partially operational end of 2023

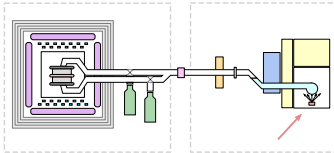


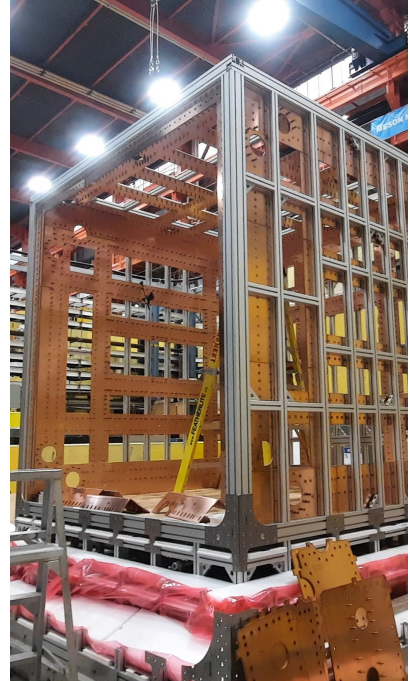
TRIUMF

→ Source to begin testing in 2023
UCN in 2024!

→ EDM measurement tools in earlier stages, but progressing quickly

→ **Goal**: measure the nEDM to 10^{-27} e · cm in <400 measurement days





TUCAN
TRIUMF Ultra Cold Advanced Neutron source

Discovery, accelerated

(END)