Automated Purification of Polarized Xe for Comagnetometry

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TUCAN Collaboration Meeting

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University of Manitoba

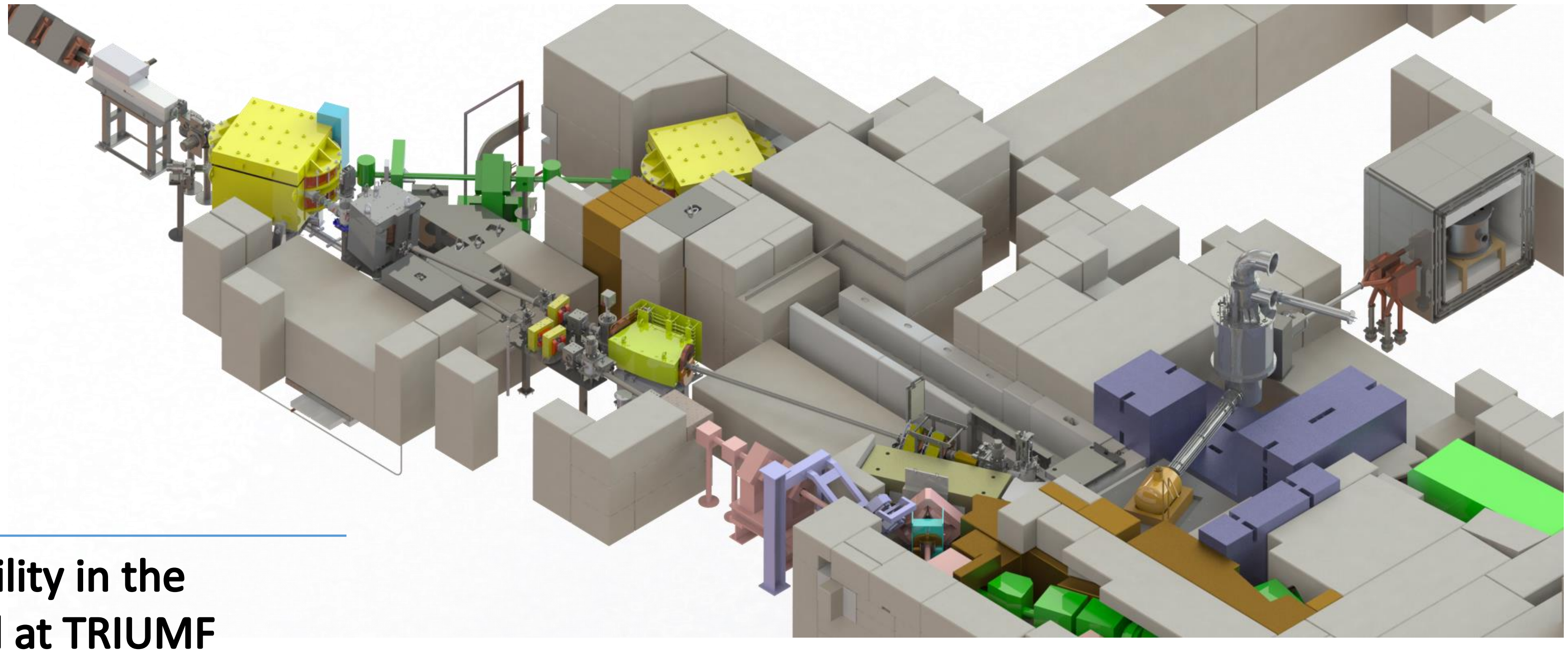
The University of Winnipeg

TRIUMF

Canada's national laboratory for particle and nuclear physics

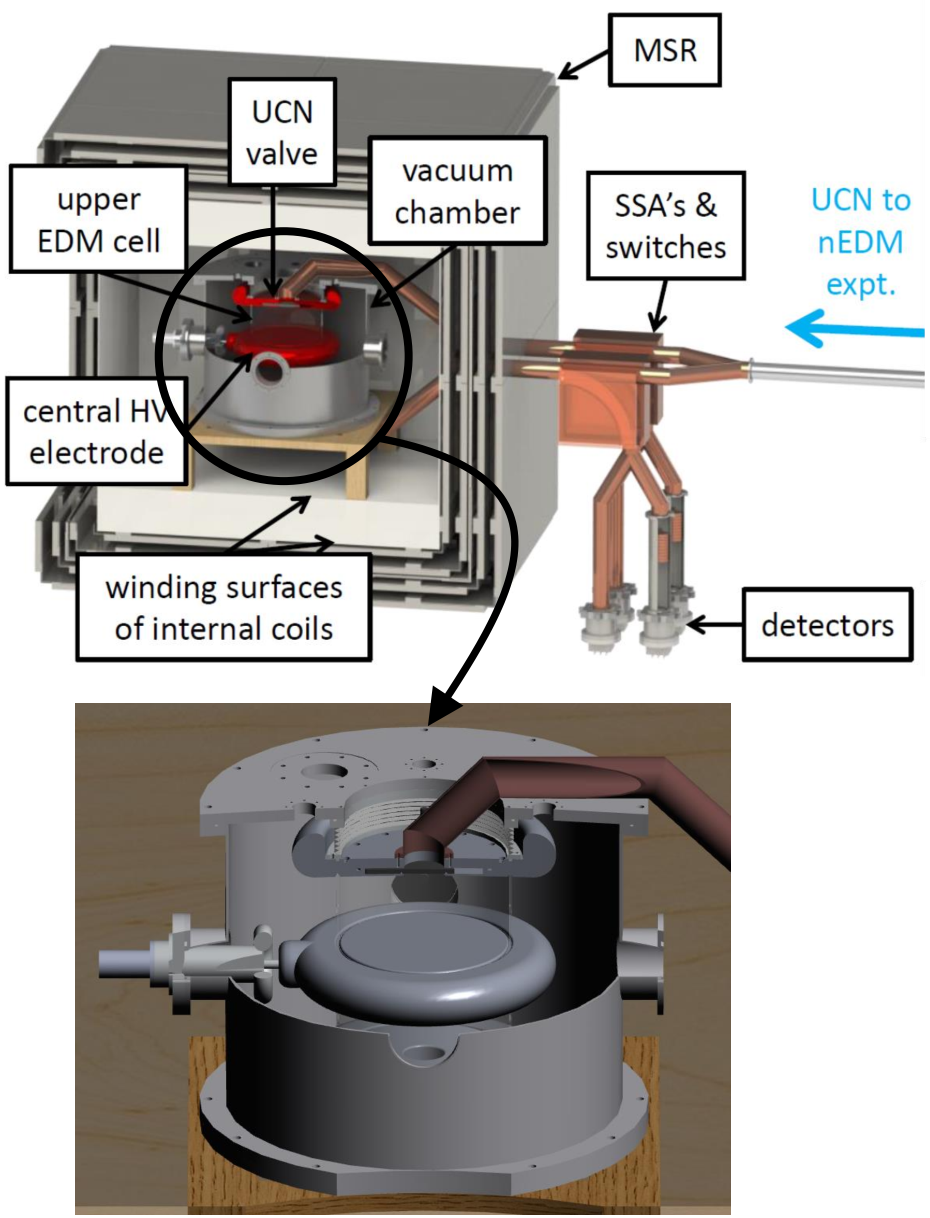
The TUCAN nEDM Experiment

- Search for charge-parity violation within/beyond standard model
- Neutron electric dipole moment (nEDM) with goal precision of $<10^{-27}$ e·cm (Starting 2020)
- Precision measurement of neutron precession frequency
- Newly developed, high-density spallation Ultra-Cold Neutron Source



TUCAN facility in the Meson hall at TRIUMF

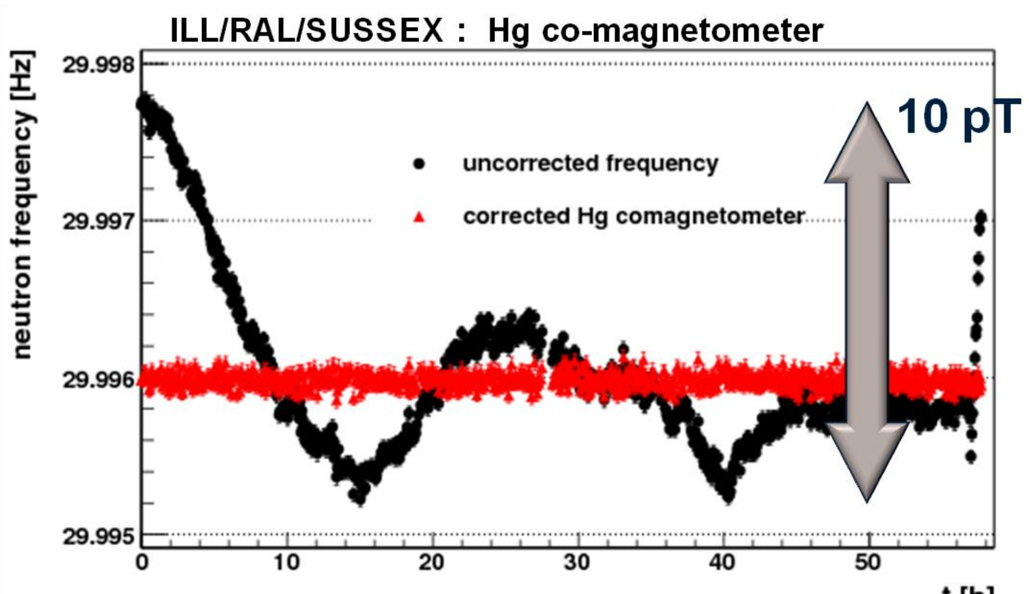
The nEDM Experiment



Required B-field precision ~10 fT

Purpose of the Comagnetometer

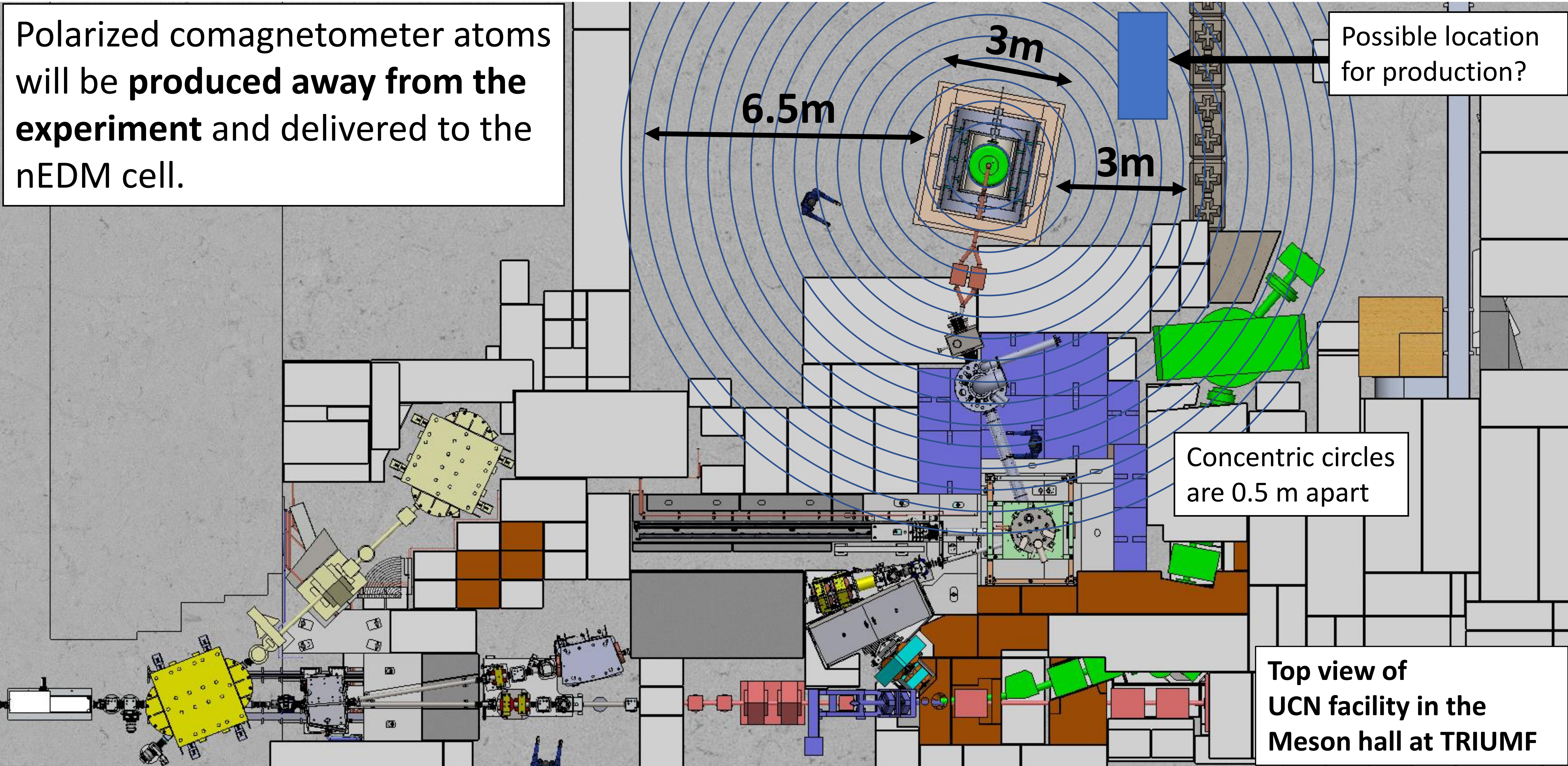
- Measure Larmor precession of another species within UCN cell
- Measure magnetic field to ~10 fT in 100s
- Proposed dual species (^{199}Hg/ ^{129}Xe) comagnetometer
- **Xe comagnetometer requires mTorr pressure of pure, highly polarized Xe in the nEDM cell**



Afach et al. EPJD 69, 1 (2015)

Comagnetometer Production and Delivery

Polarized comagnetometer atoms will be **produced away from the experiment** and delivered to the nEDM cell.

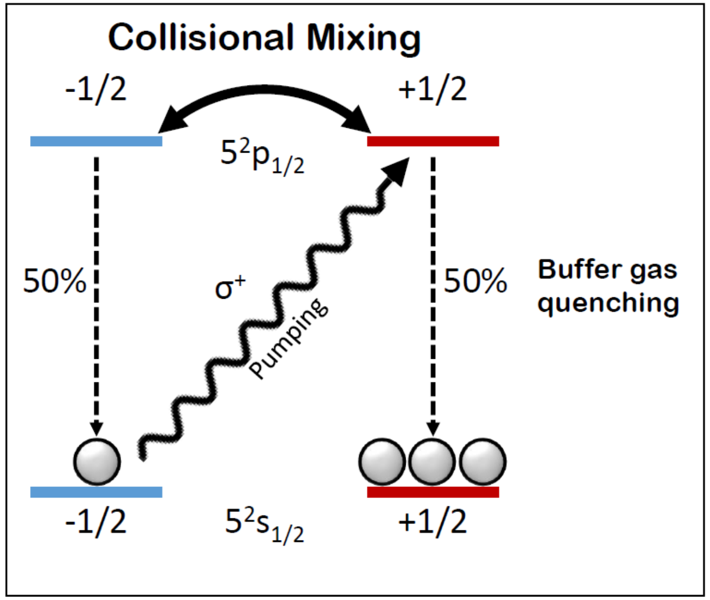


Top view of UCN facility in the Meson hall at TRIUMF

Polarized Xe Production and Purification

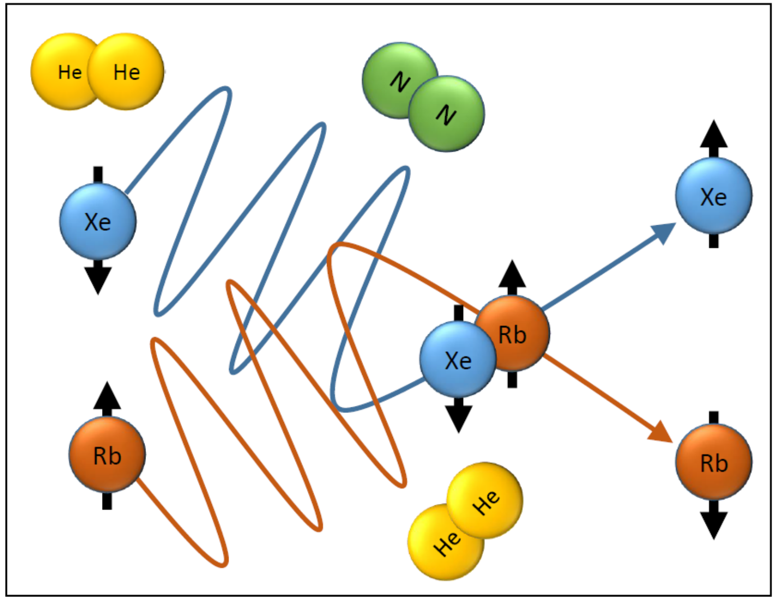
Polarize Rb → Transfer polarization to Xe → Purify polarized Xe

Rb Optical Pumping

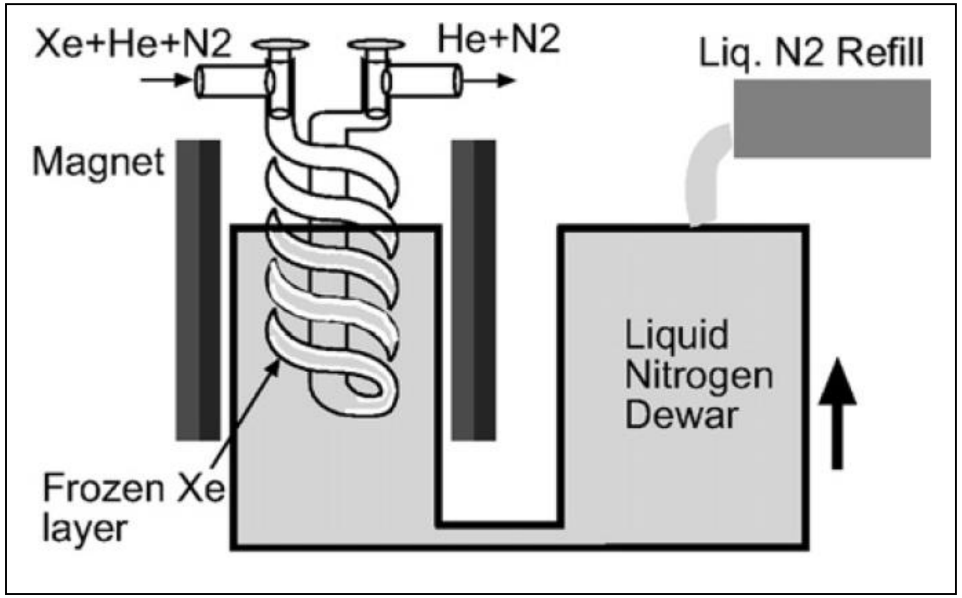


Rev. Mod. Phys., Vol. 69, No. 2, April 1997

Rb-Xe Spin-Exchange



Freezeout Xe in a magnetic field



Hersman et al. Academic Radiology, Vol 15, No 6, June 2008

Our SEOP system uses a gas mixture of 1% Xe, 3% N_2, and 96% He

Requirements for Purification System

Freezeout Cell: Sufficient surface area for thin deposition of condensed Xe during purification by freezeout

Magnetic Field: Sufficiently strong to prevent rapid depolarization of condensed Xe during freezeout/recovery

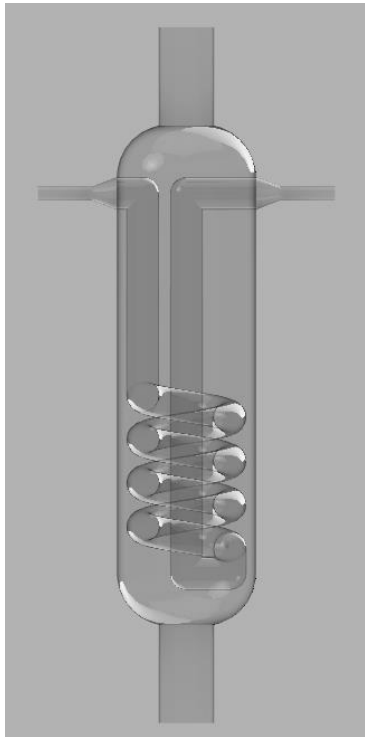
Xe Recovery: Rapid sublimation to reduce time spent in Xe solid phase, especially near the triple point

Xe Gas Handling: Non-magnetic materials that preserve Xe polarization

Freezeout Cell

The TUCAN experiment requires 1 - 10 mTorr pure Xe pressure in ~33 litre volume
→ 0.033 - 0.33 Torr*litres Xe

- **Design based on 99.8% recovery in [1] where 45 cm^2 of surface area per Torr*litre of Xe was used**
- **Xe condensing area ~200 cm^2**
- **Suitable for at least ~4.4 Torr*litres of Xe accumulation**
- **Single purification run could supply over 100 nEDM runs worth of Xe**



Design

Initial production

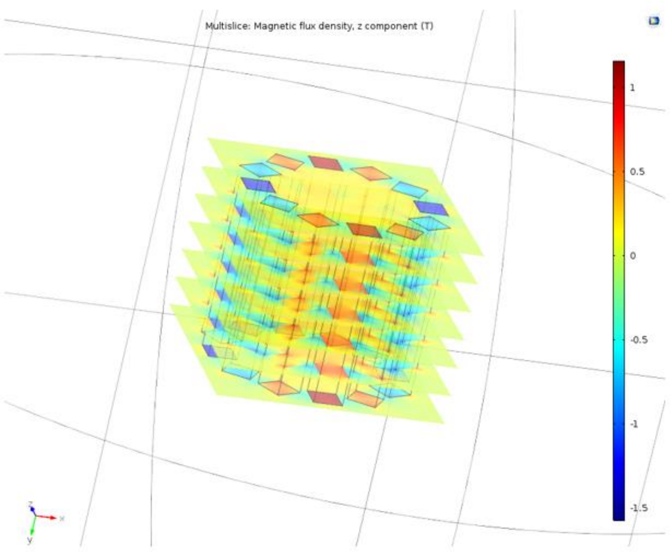
Final cell with modifications

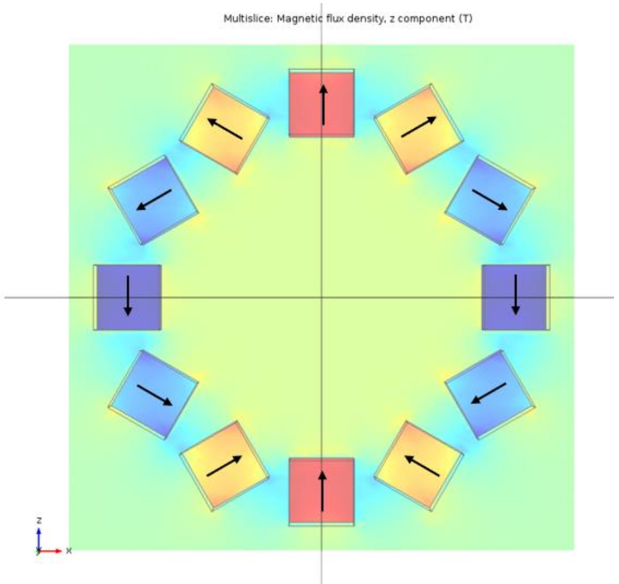
Note: 4.4 Torr*litres is 55 Torr in 80 ml cold trap

[1] Hersman et al. Academic Radiology, Vol 15, No 6, June 2008

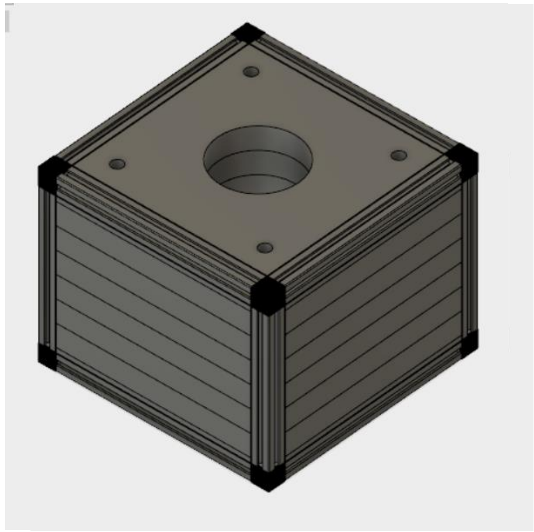
Halbach Array for Xe Purification B-Field

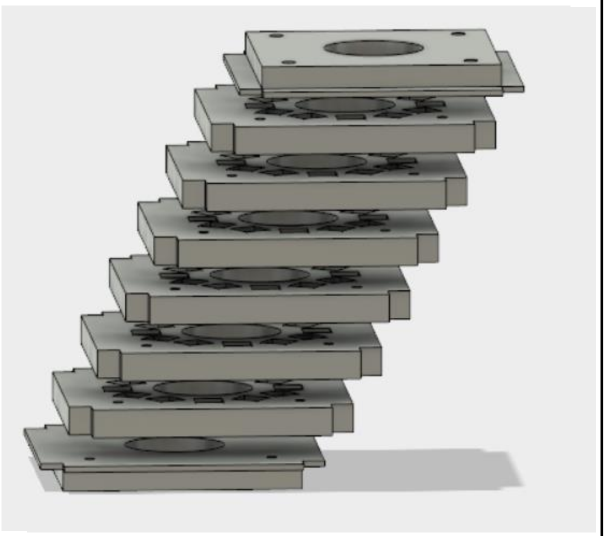
Comsol Simulation

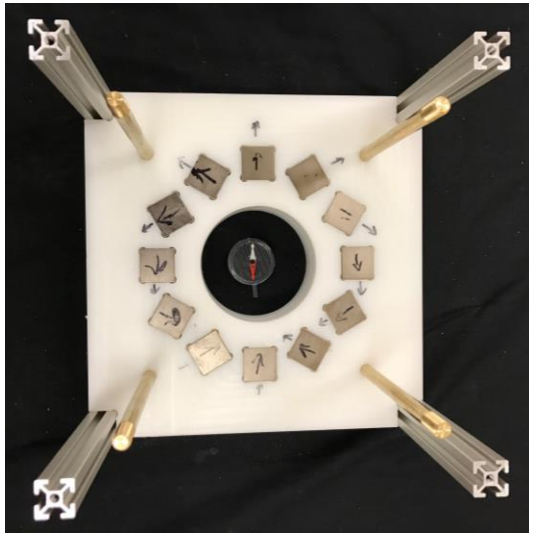




CAD Model



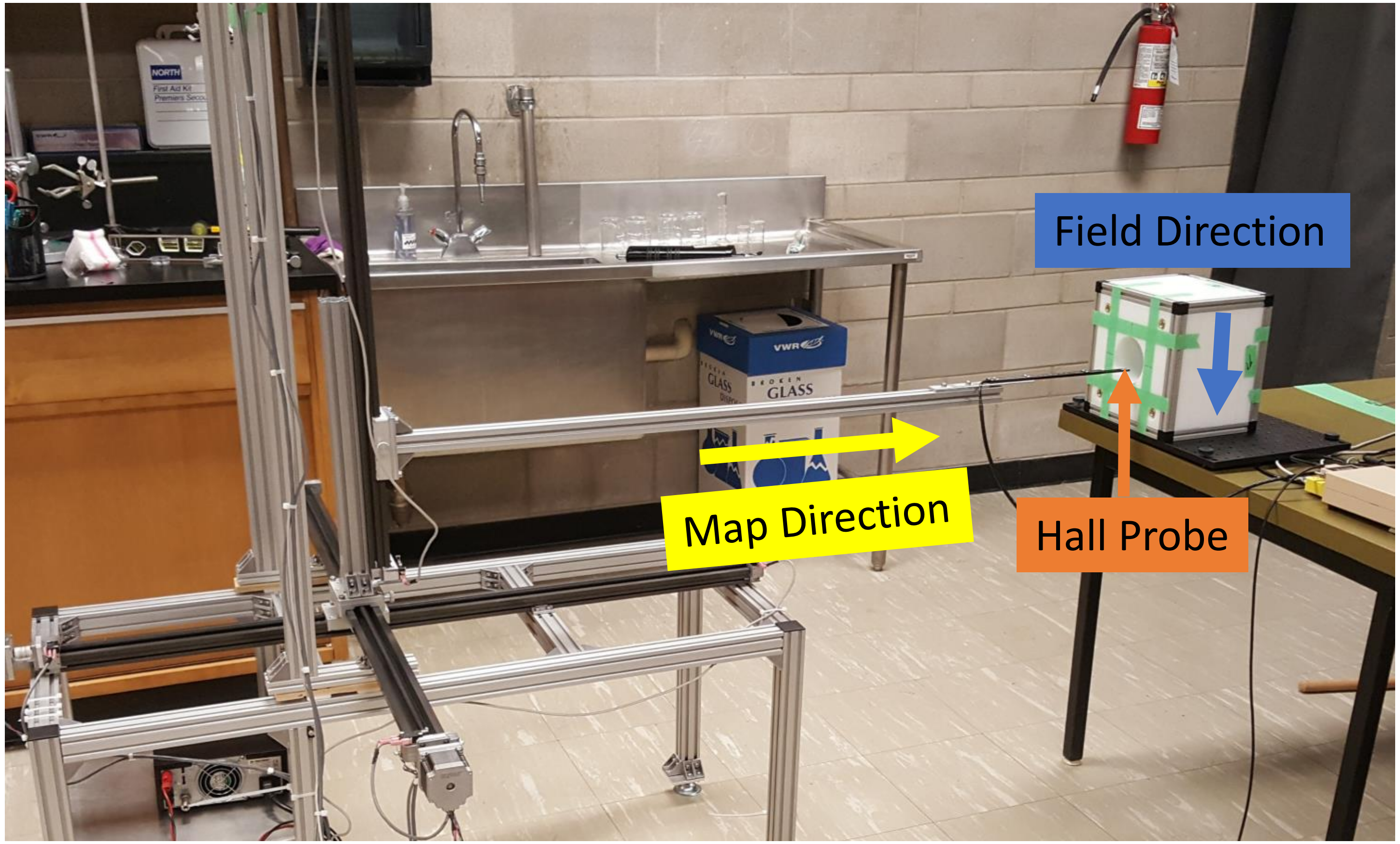




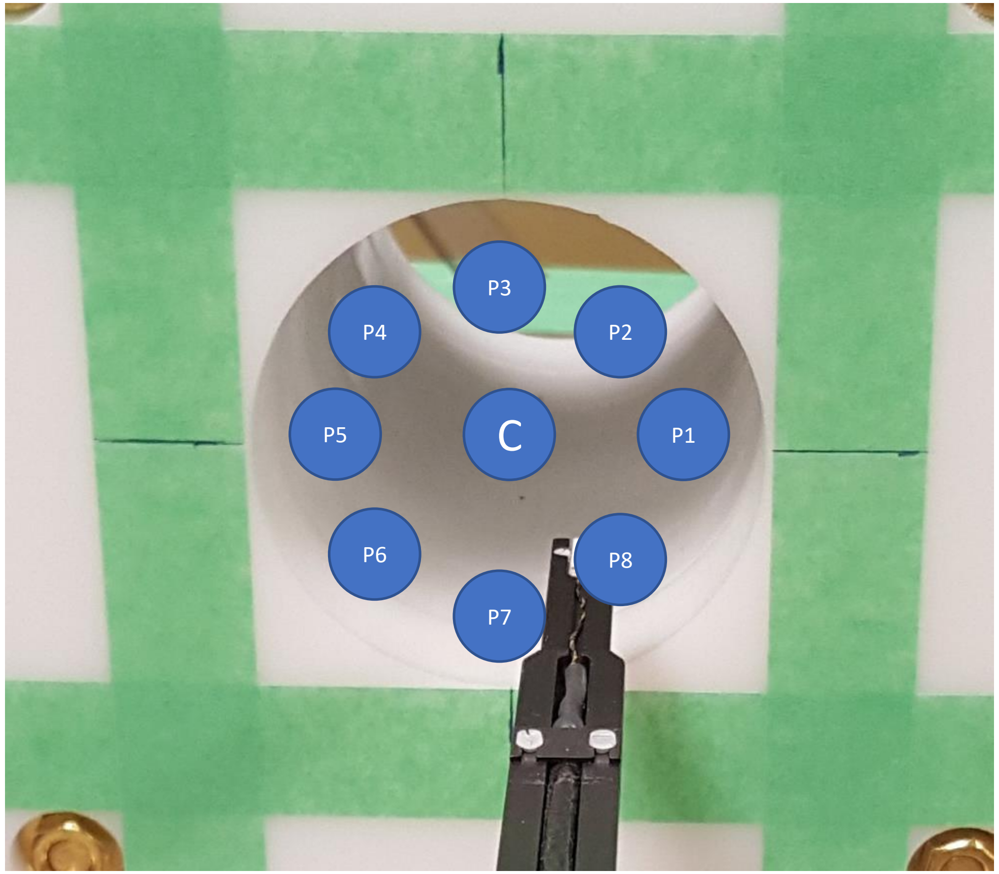
← Completed Halbach array

- Total size is 10”length x 10”width x 8” height
- 3.5” diameter central bore
- 72, 1” cube N52 magnets
- 6 layers of 12 magnets in K =2 Halbach ring configuration

Field Mapping the Halbach Array



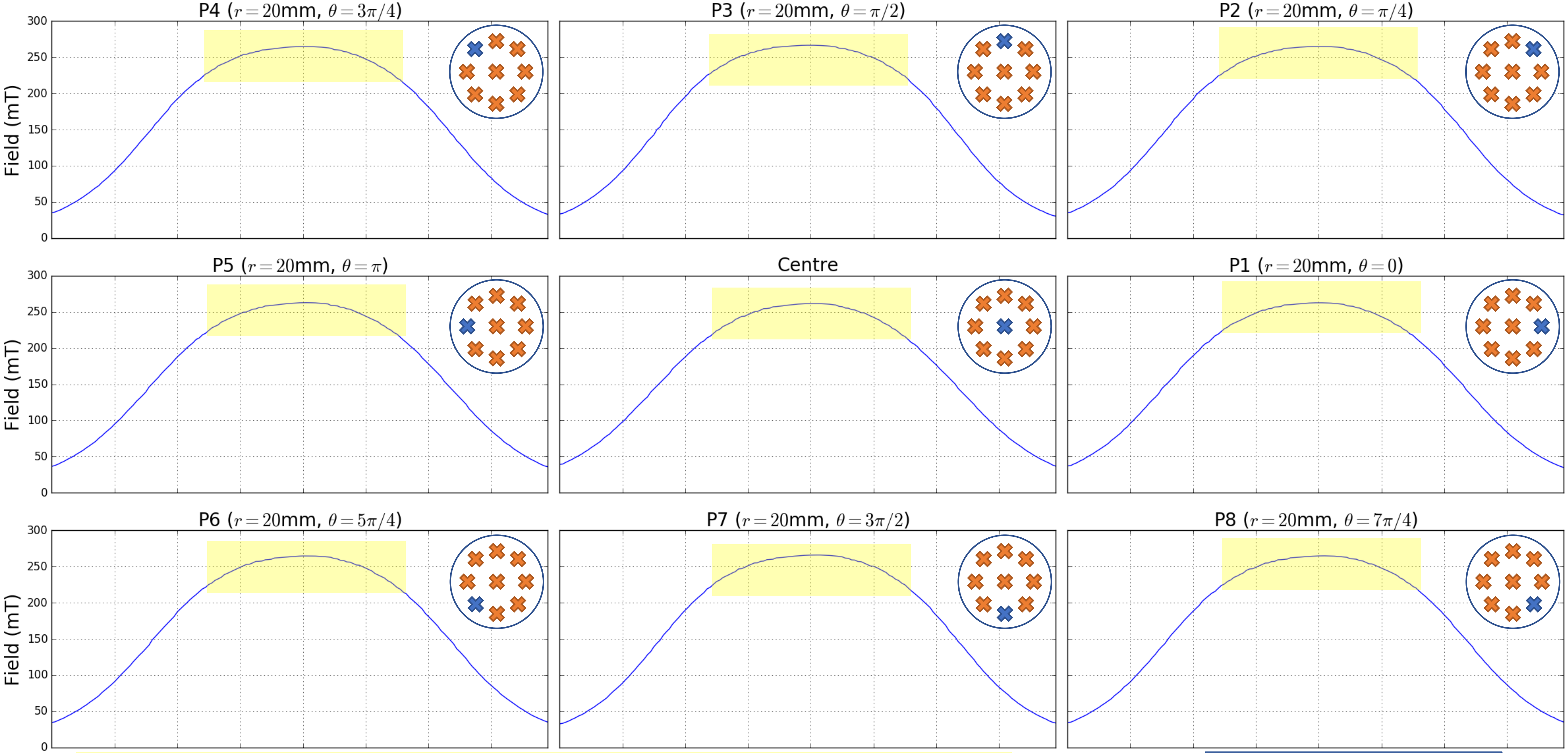
Mapping layout



Mapping points

- Hall probe with 5 μT resolution used for field measurements
- Locations are the center of the bore, and 8 points located ~20 mm radially from the center at 45 degree increments
- Each field profile starts and ends ~25mm outside of each end of the bore

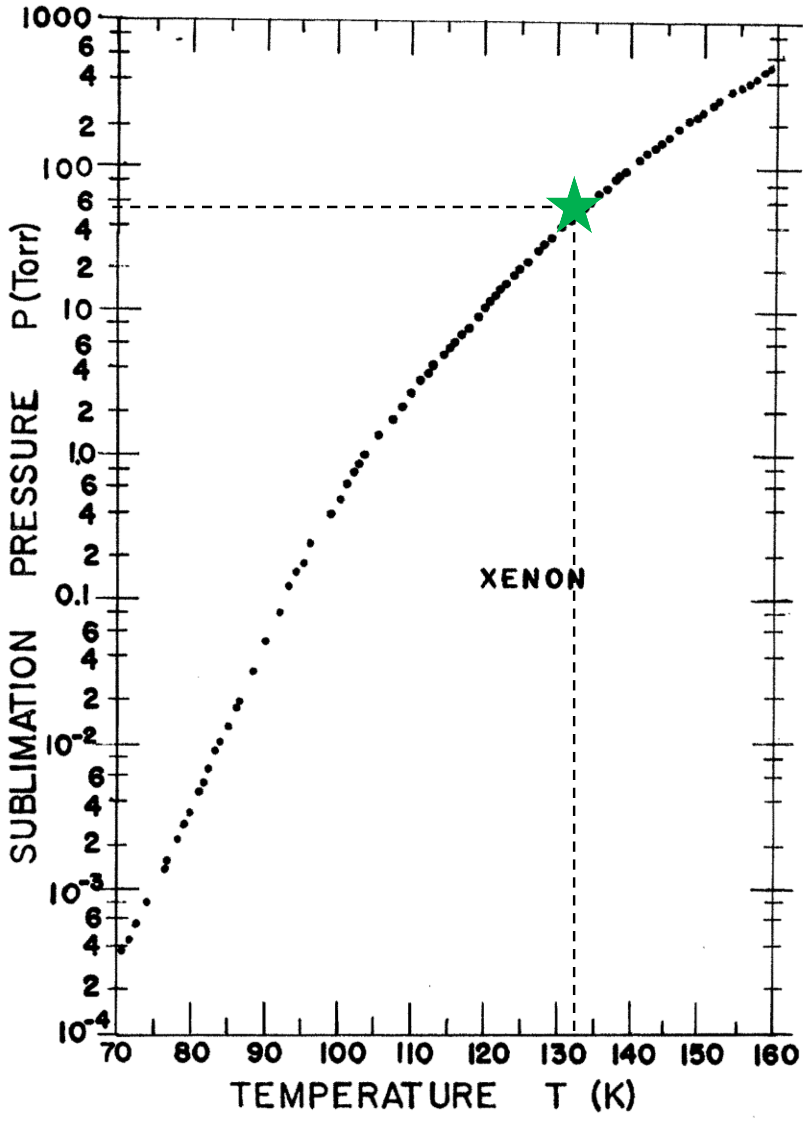
Halbach Array Field Map



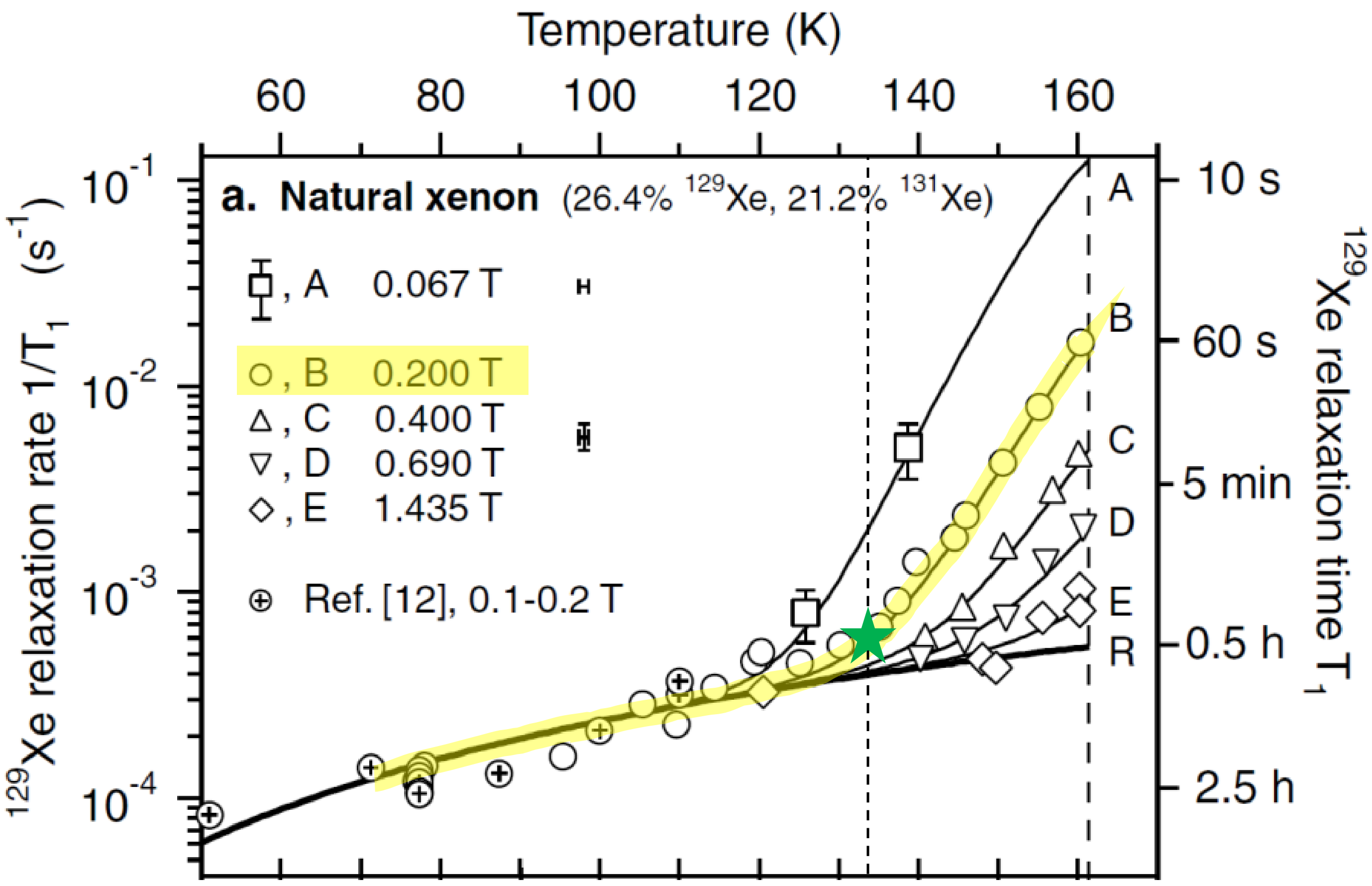
Xe cold trap is located in the central region where the B-field is 225-260 mT

Field map position ✖

Solid Xe Sublimation Temperature and Spin Relaxation



Sublimation Pressure of Solid Ar, Kr, and Xe
Phys. Rev. B, 2(8), 3323

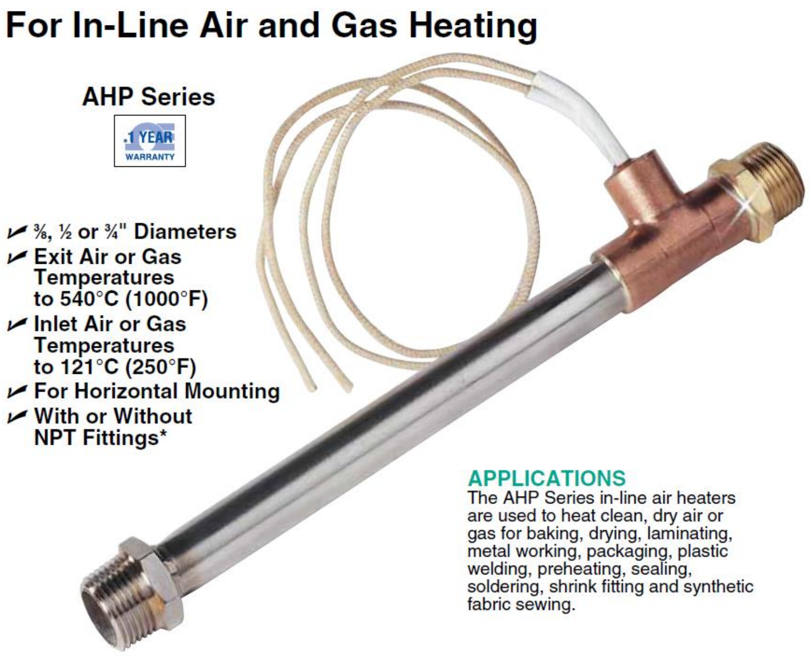


Fast Nuclear Spin Relaxation in Hyperpolarized Solid ^{129}Xe
Phys. Rev. Lett., 88(14), 147602

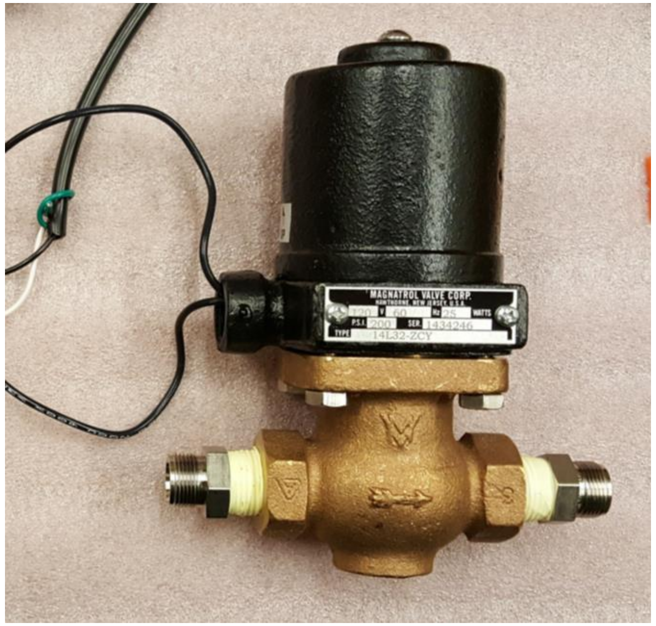
★ At 55 Torr, Xe sublimates at 135 K

Xe Recovery

- Heated air used to evacuate LN2 from cold trap and sublimate frozen Xe in < 50 s



Inline heater with airline provides ample supply of hot air at pressure up to 80 PSI

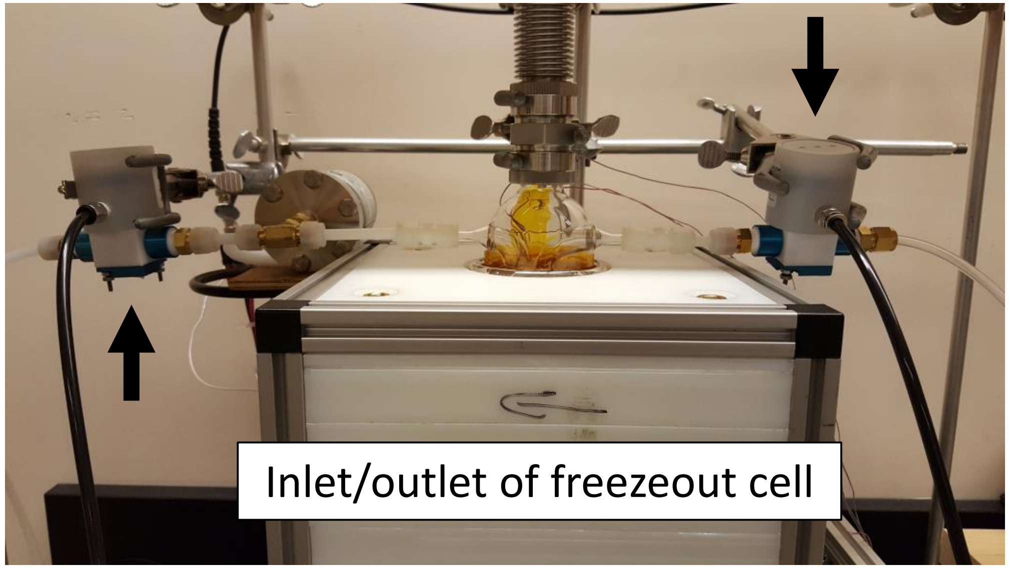


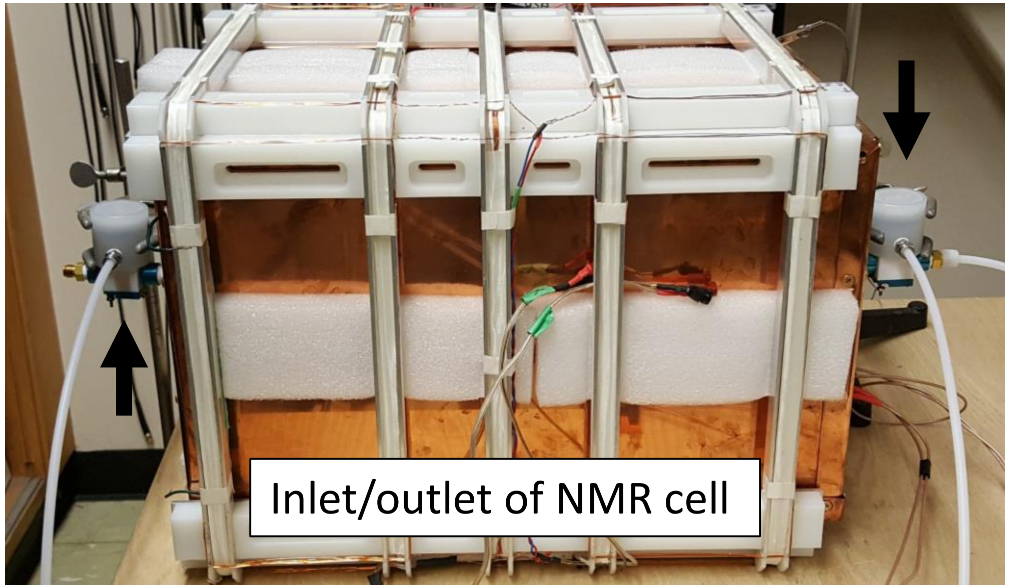
High temperature valves are actuated electronically to control heated air flow

Polarized Xe Gas Handling

<u>International Polymer Solutions (IPS) P/N MTV-442CFS-T</u>

- 1/4” FNPT & 0.250” Orifice
- 2-Way Normally Closed
- PTFE Valve Seat
- Pneumatically Actuated





Automation, Control, and Monitoring

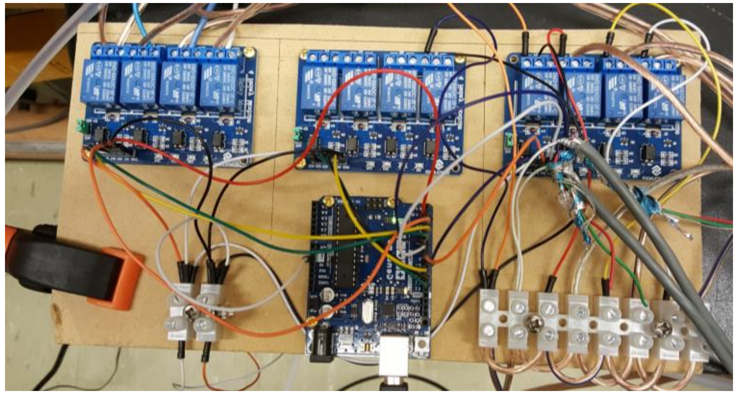
- System controlled via python code on local PC
- Arduino microcontroller receives commands from the PC and engages electronic and pneumatic valves through relays

- Pressure monitored with Baratron capacitance manometer

- Thermocouples monitor cold trap temperature

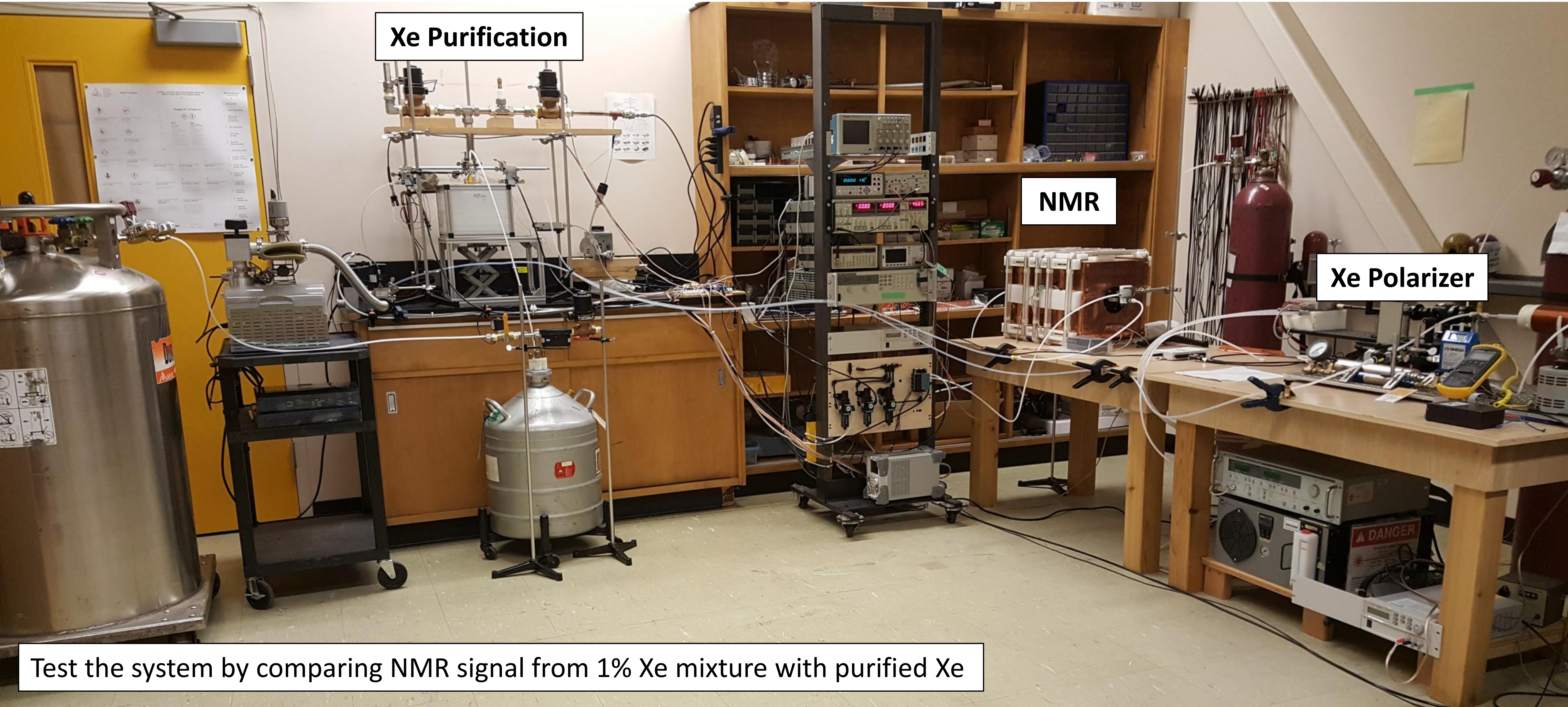
- Flow meter monitors Xe gas mixture flow rate

Arduino and relay boards



Compressed air gas panel

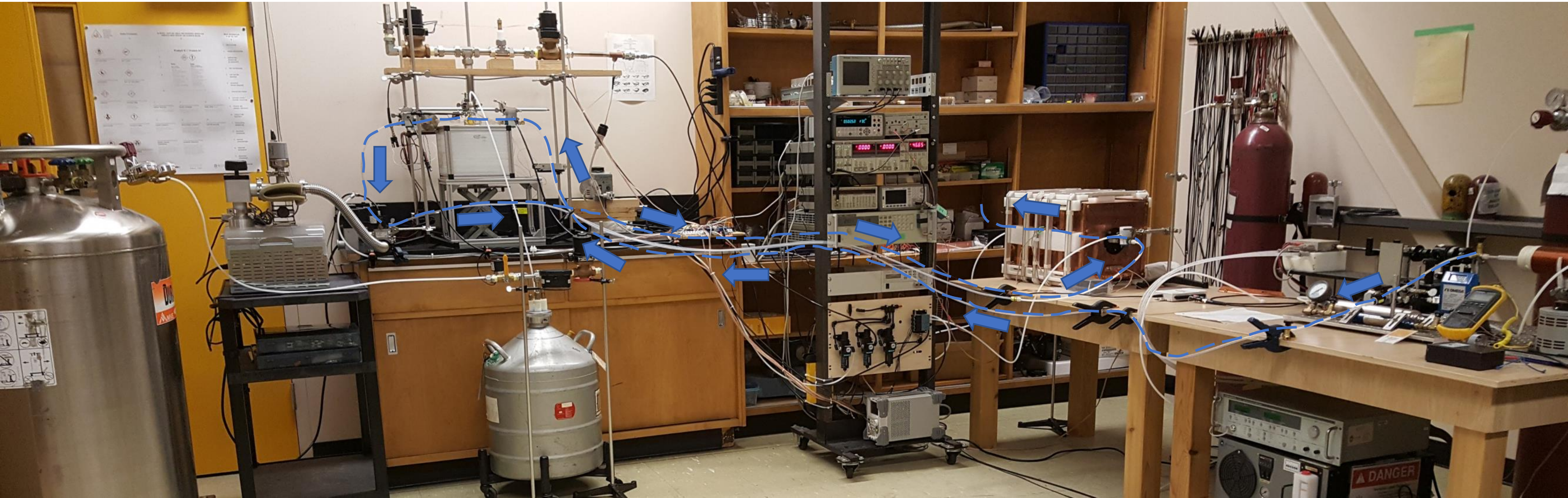
Experimental Setup



Test the system by comparing NMR signal from 1% Xe mixture with purified Xe

Acquire 1% Xe mixture signal:

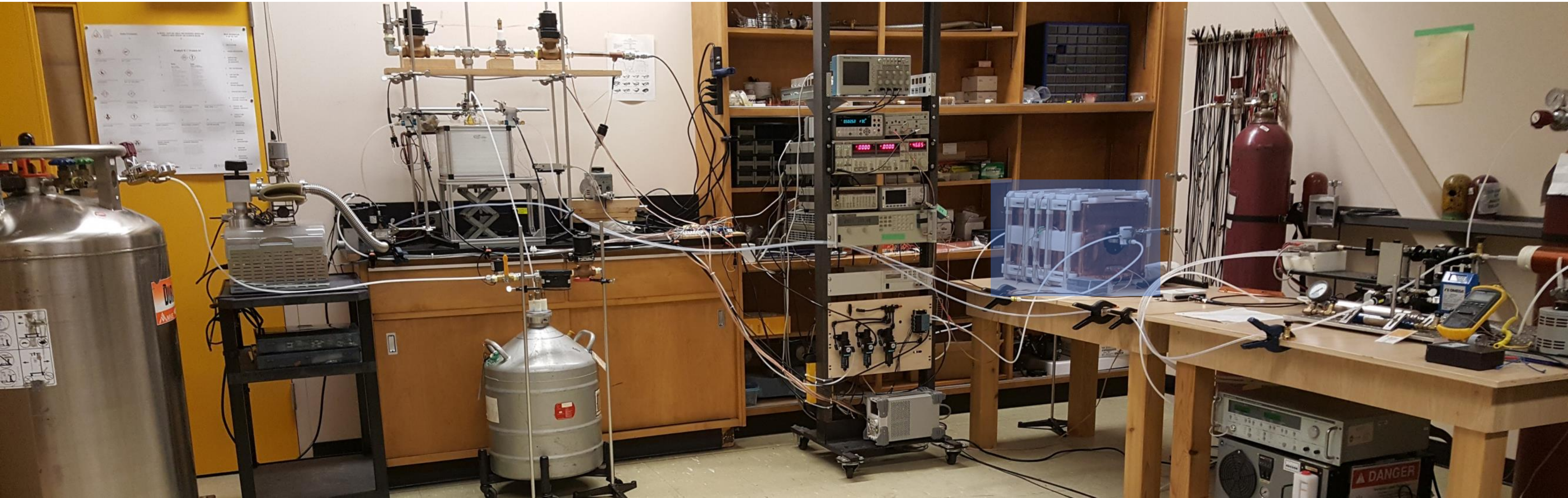
1) Flow Xe gas mixture through entire system (Polarizer, cold trap, NMR cell)



Acquire 1% Xe mixture signal:

1) Flow Xe gas mixture through entire system (SEOP, cold trap, NMR cell)

2) Close pneumatic valves around NMR cell to trap gas

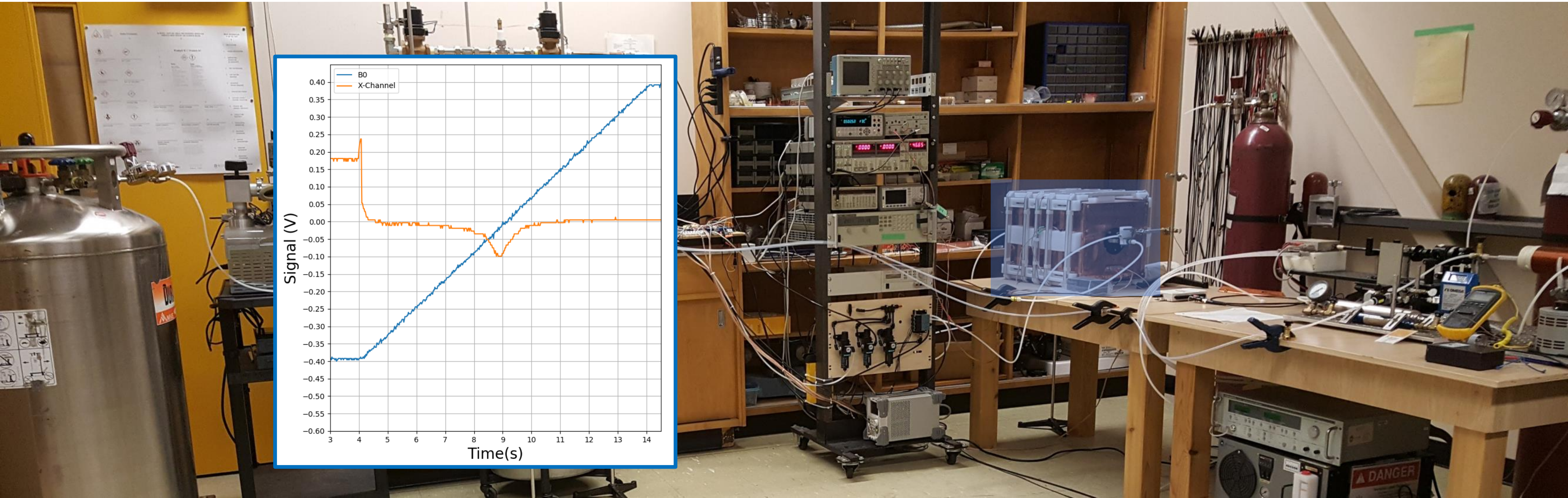


Acquire 1% Xe mixture signal:

1) Flow Xe gas mixture through entire system (SEOP, cold trap, NMR cell)

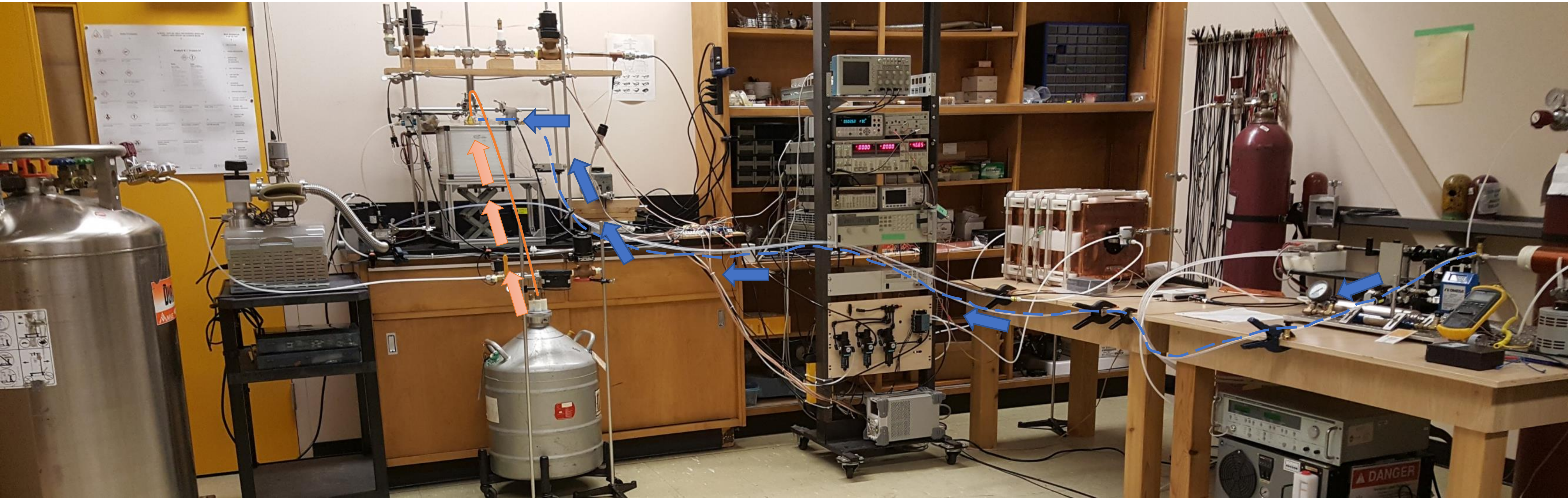
2) Close pneumatic valves around NMR cell to trap gas

3) Acquire NMR signal



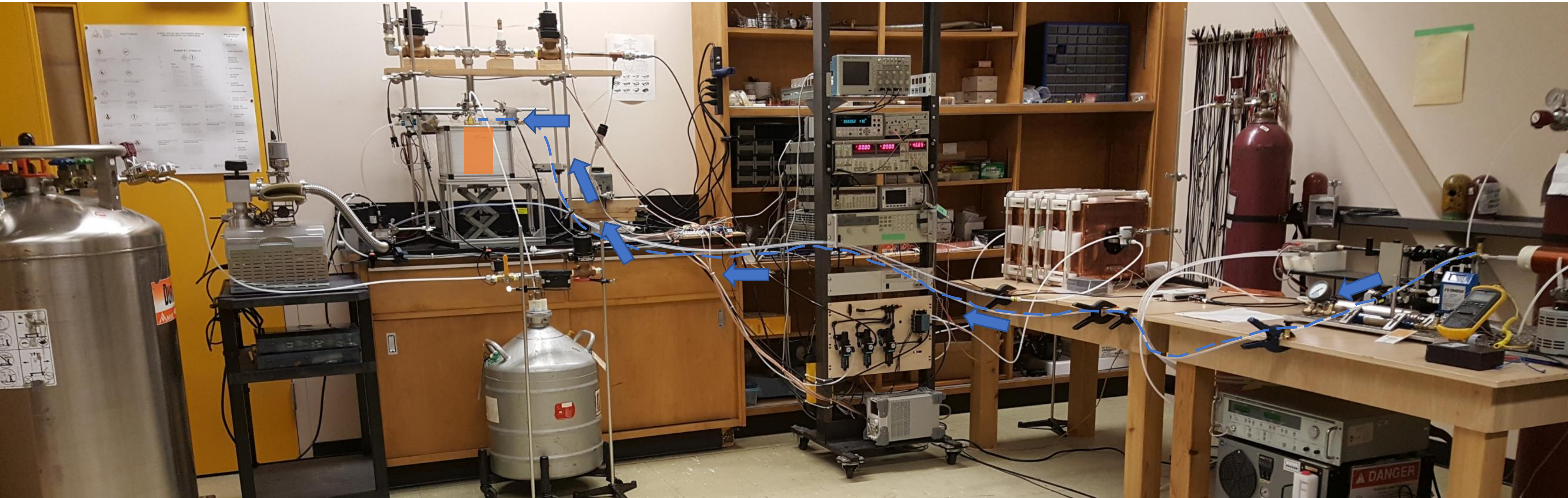
Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture



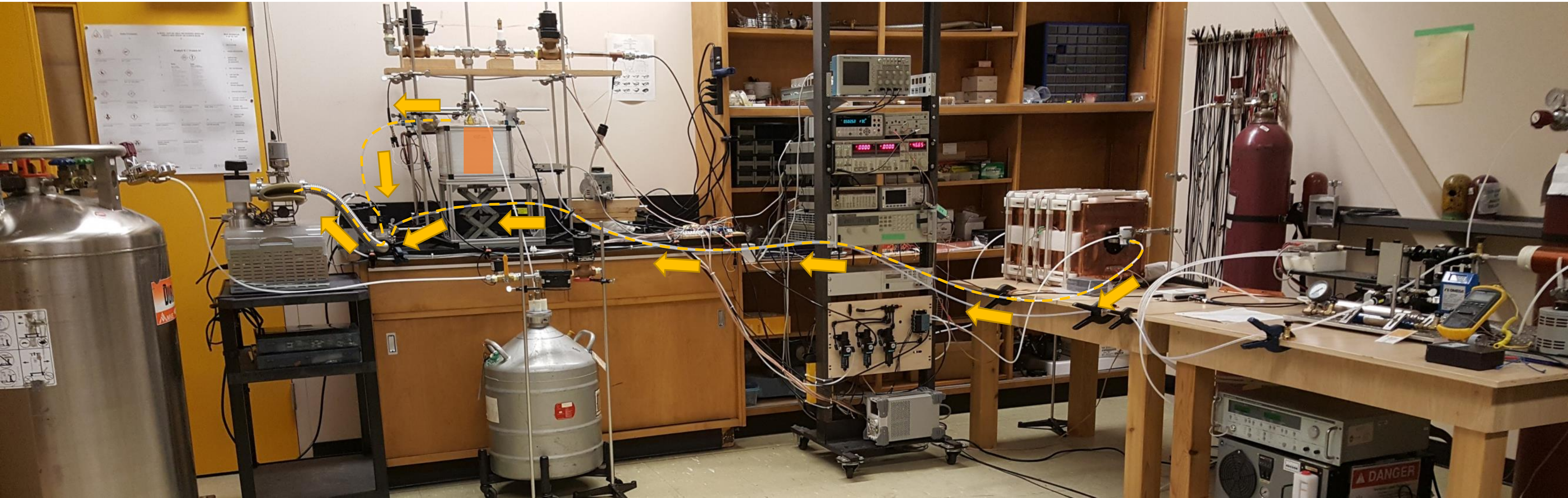
Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture
2) Hold LN2 while continuing Xe gas mixture flow



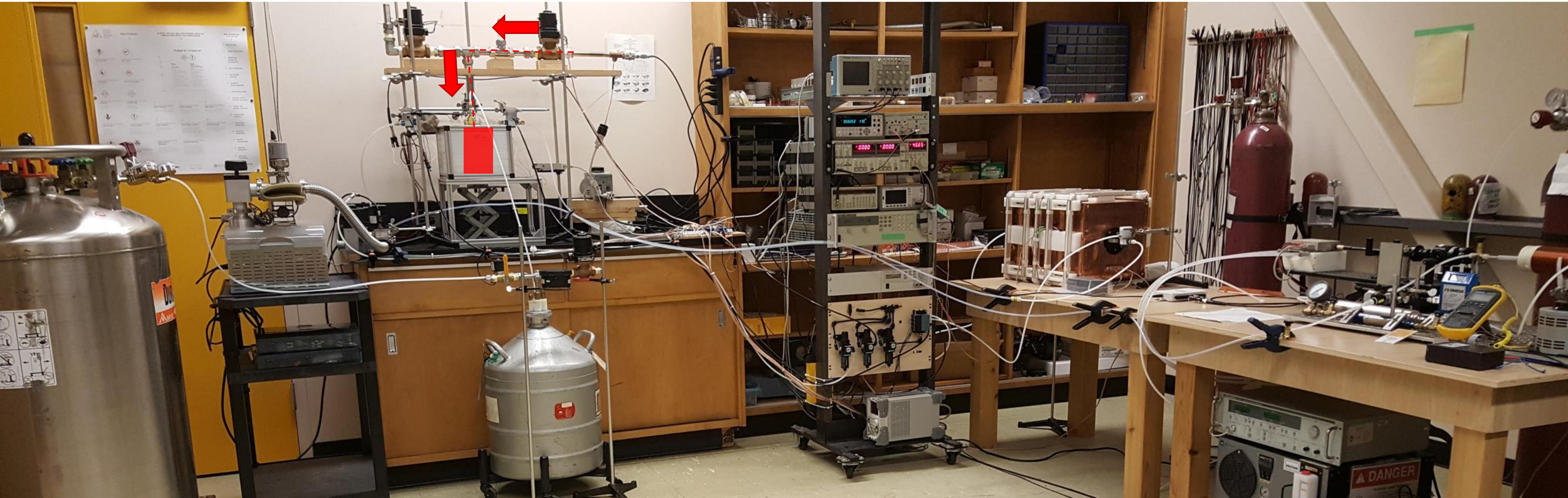
Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture
2) Hold LN2 while continuing Xe gas mixture flow
3) Stop Xe gas mixture flow and pump on cold trap & NMR cell to remove buffer gas



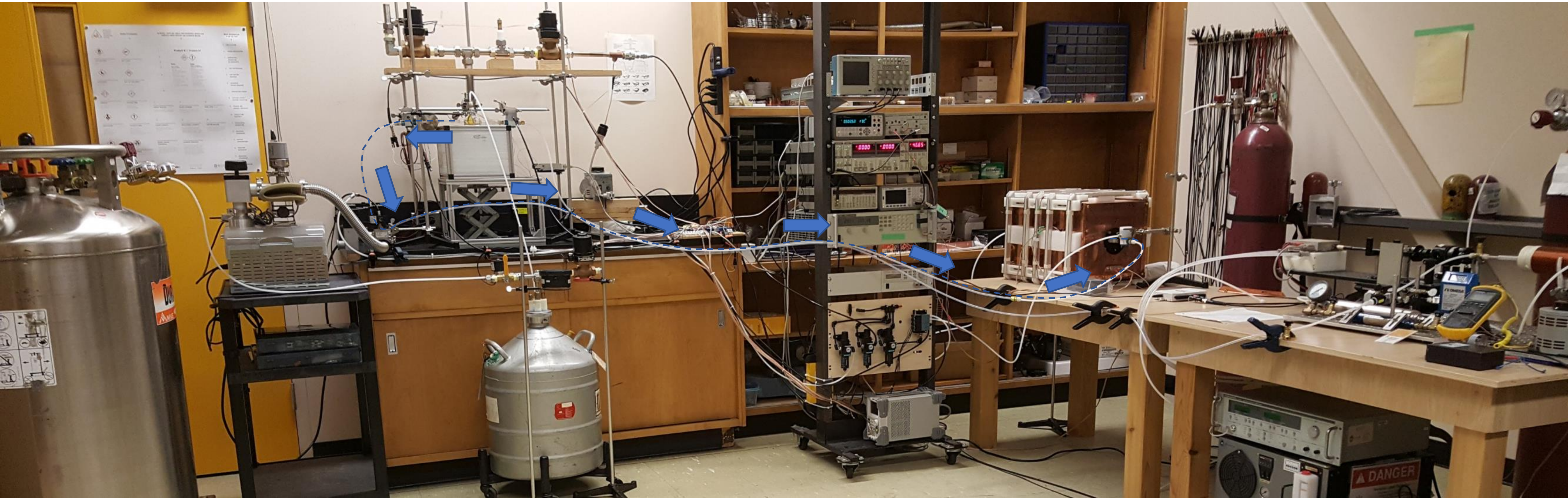
Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture
2) Hold LN2 while continuing Xe gas mixture flow
3) Stop Xe gas mixture flow then pump down cold trap to remove buffer gas
4) Close cold trap valves and heat to sublimate frozen Xe



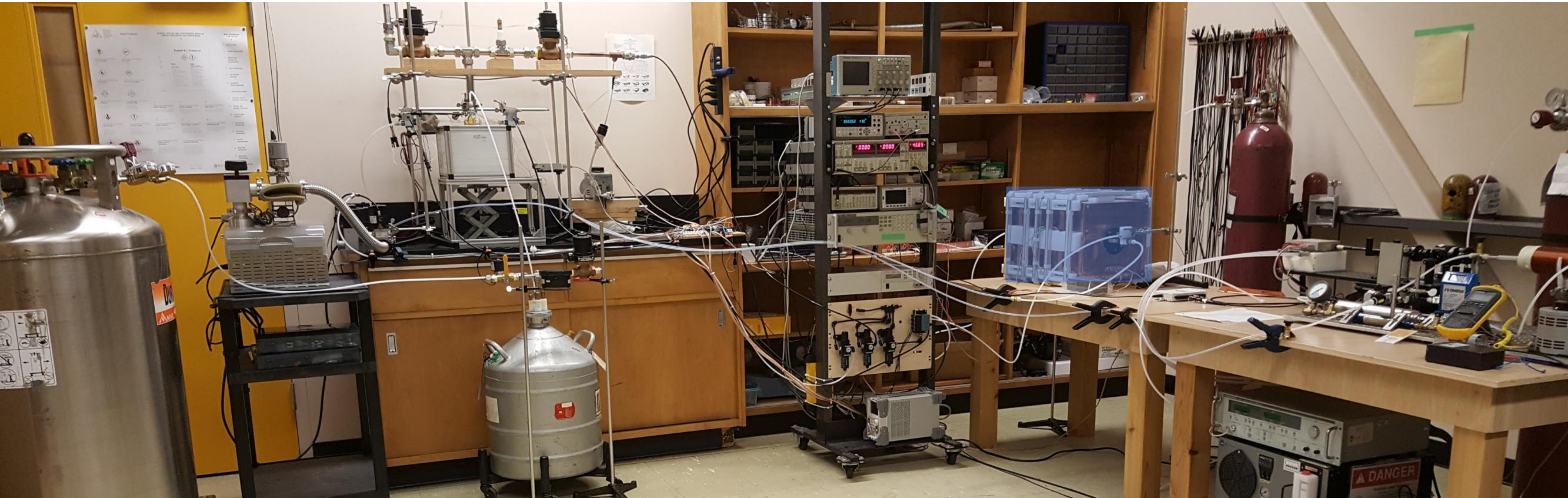
Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture
2) Hold LN2 while continuing Xe gas mixture flow
3) Stop Xe gas mixture flow then pump down cold trap to remove buffer gas
4) Heat cold trap to sublimate frozen Xe
5) Expand cold trap contents into NMR cell



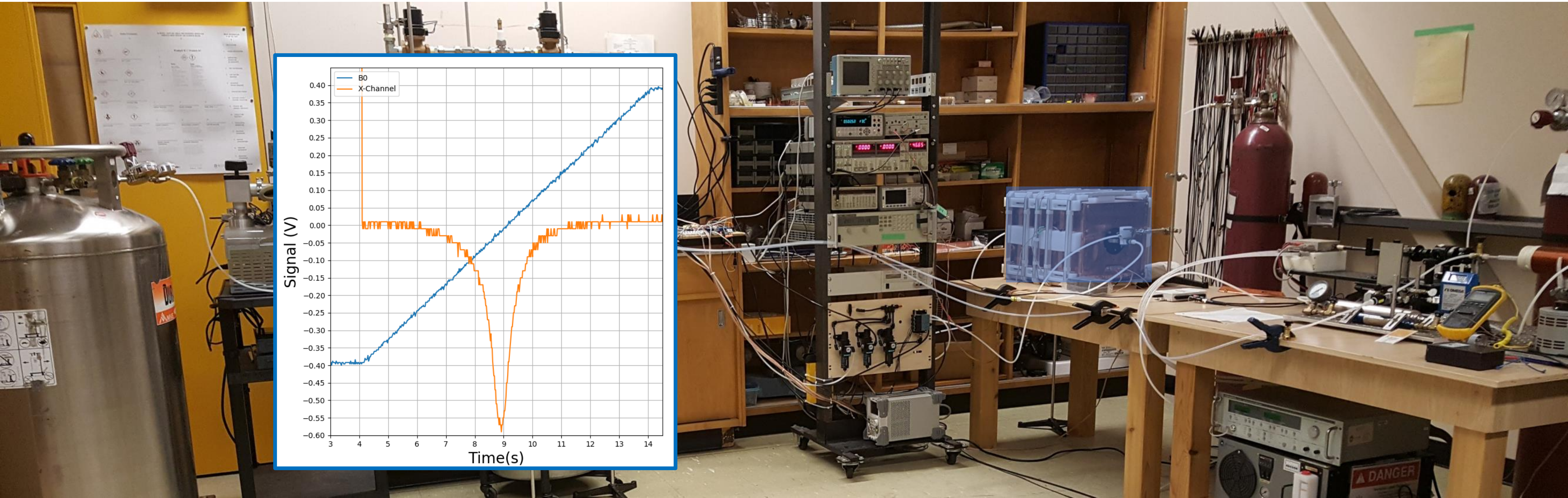
Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture
2) Hold LN2 while continuing Xe gas mixture flow
3) Stop Xe gas mixture flow then pump down cold trap to remove buffer gas
4) Heat cold trap to sublimate frozen Xe
5) Expand cold trap contents into NMR cell
6) Trap Xe in NMR cell

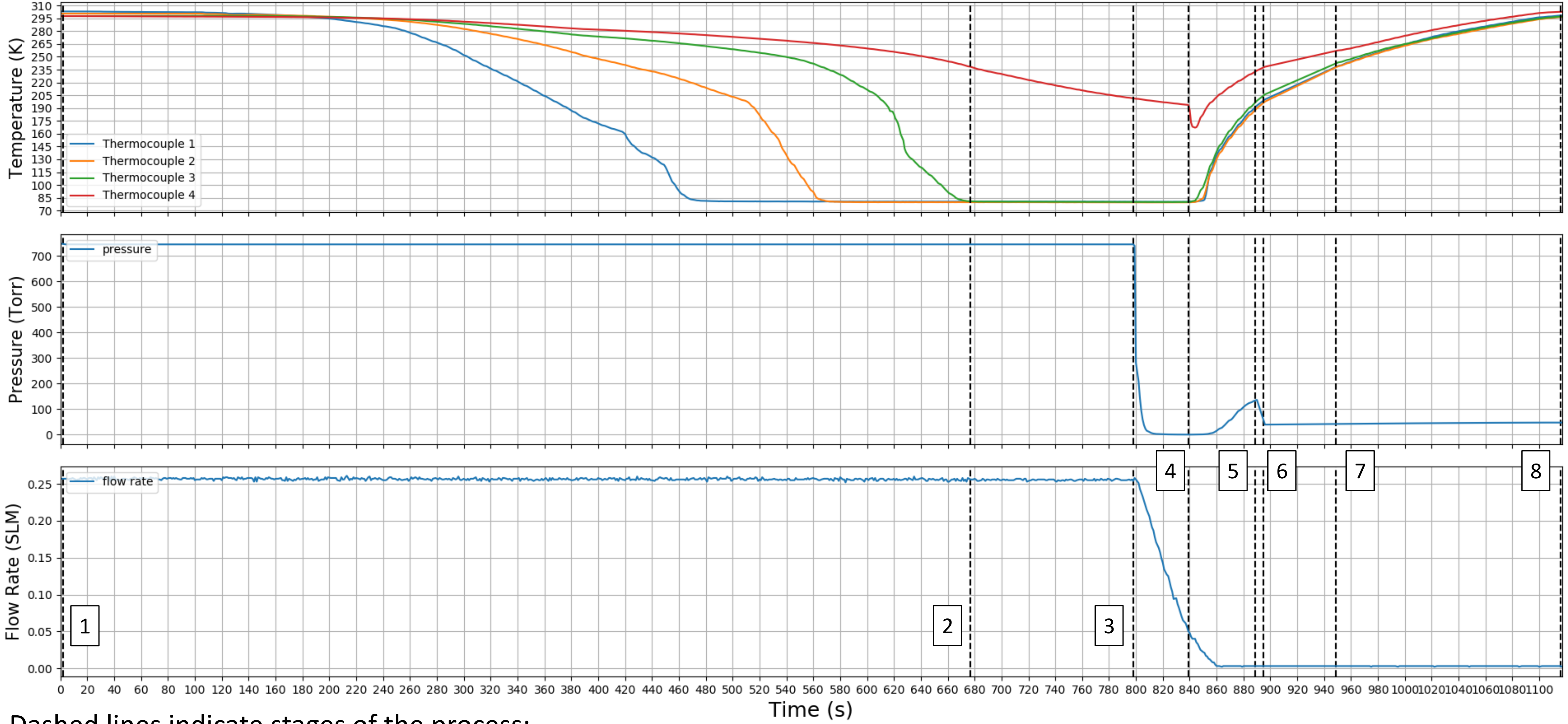


Acquire purified Xe signal:

1) Fill cold trap dewar with LN2 while flowing Xe gas mixture
2) Hold LN2 while continuing Xe gas mixture flow
3) Stop Xe gas mixture flow then pump down cold trap to remove buffer gas
4) Heat cold trap to sublimate frozen Xe
5) Expand cold trap contents into NMR cell
6) Trap Xe in NMR cell
7) Acquire NMR signal



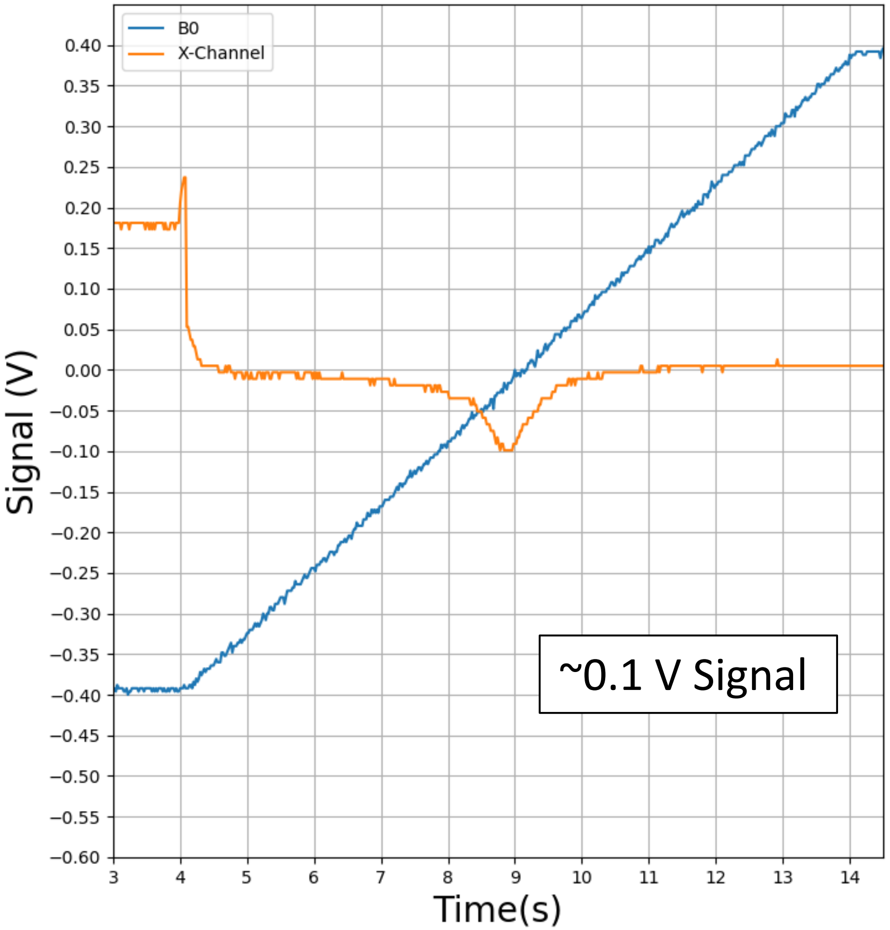
Xe purification run



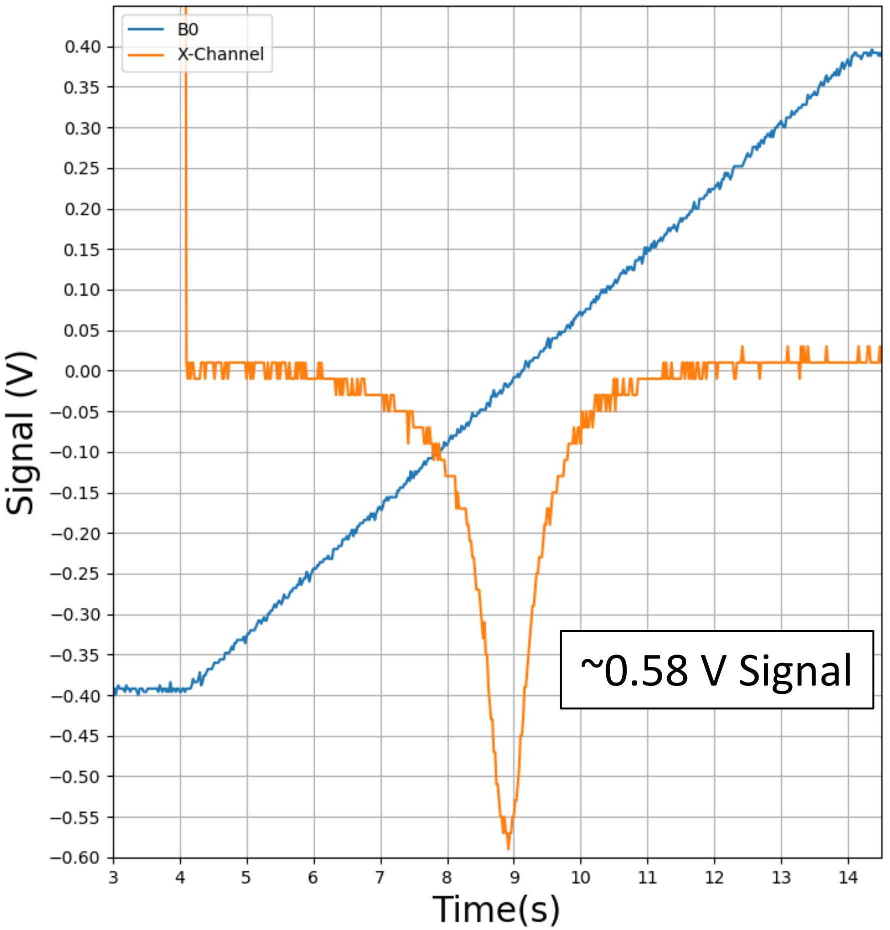
Dashed lines indicate stages of the process:

1) Begin filling LN2 while flowing Xe
2) Stop filling and hold LN2
3) Stop Xe flow and pump cold trap
4) Evacuate LN2 and heat cold trap
5) Expand cold trap contents into NMR cell
6) Trap Xe and perform AFP sequence
7) Warm cold trap to room temp
8) Cool down inline heater and end sequence

745 Torr of 1% Xe Mixture



39.6 Torr of Purified Xe



Pressure ratio: $\frac{39.6\ Torr\ Xe}{7.45\ Torr\ Xe}$ = 5.32

Signal ratio: $\frac{0.58\ V}{0.1\ V}$ = 5.8

- **Discrepancy in signal/pressure could be due to gas temperature and flow rates**

Next steps:

- Build T-Slot frame for the purification system → Stand alone apparatus
- Perform more rigorous testing and characterisation
- Investigate transportation of Xe → are guide fields necessary?
- Use RGA to check purity of Xe
- Ship system to UBC for testing with Xe spectroscopy and 2-photon LIF

Thank you!