Systematics and Operational Studies (SOS) Apparatus for the nEDM@SNS Experiment

R. Adam Dipert
Arizona State University
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Abstract

The Systematic and Operational Studies (SOS) apparatus, being designed for the PULSTAR reactor at NC State University, is a test bed for the Neutron Electric Dipole Moment (nEDM) experiment at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. The PULSTAR-SOS apparatus and SNS-nEDM experiment will have many physically similar conditions, including (a) temperature near 400 mK, (b) the same measurement cell design, size, and wavelength shifter, (c) use of a Superconducting QUantum Interference Device (SQUID) magnetic detection system, and (d) the use of helium-3 as a co-magnetometer, polarization analyzer, and detector. The major difference is that the PULSTAR-SOS apparatus will not have an electric field. However, it is possible to study the major helium-3 false edm effect by means of relaxation and frequency shift measurements. Construction of the PULSTAR-SOS cryostat has begun at the Triangle Universities Nuclear Laboratory (TUNL). I will report on the plans for the experiments and systems which have been installed and tested.

Overview

The Systematic and Operational Studies (SOS) apparatus is currently housed at the Triangle Universities Nuclear Laboratories (TUNL) on Duke Campus in Durham NC. TUNL is a US Department of Energy (DOE) nuclear physics facility shared with professors, students, and postdocs between NC State (NCSU), Duke, UNC, and NC Central Universities.

Phase 1: at Duke, we will build and commission the device and complete our study of the geometric phase shift of 3He.

Phase 2: at PULSTAR, the cryostat will be placed near the PULSTAR research reactor where we will introduce Ultra-cold Neutrons (UCN) and 3He to the same measurement cell.

I came to TUNL as a graduate student at Arizona State University (ASU) in 2013, and have been here since. I received my PhD in 2019 and am now an ASU postdoc, still working at TUNL.

n-3He Capture

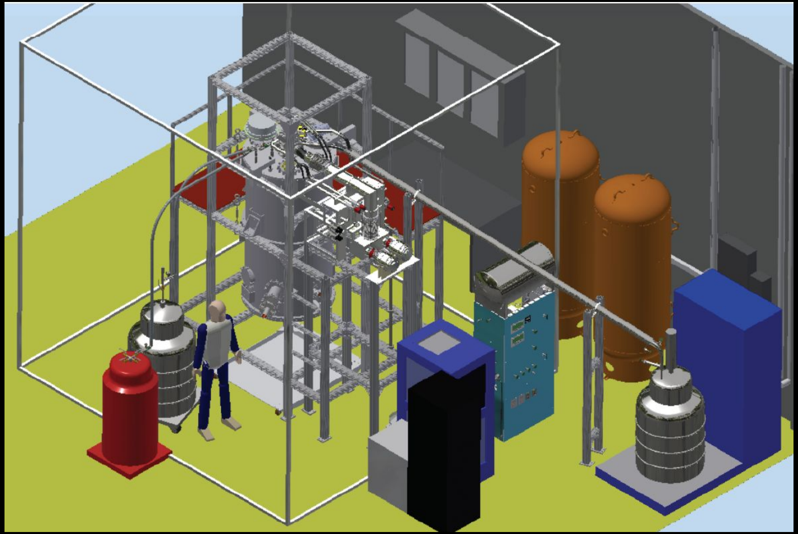
The frequency of the neutron spin will be detected by polarized helium 3. The neutron capture process is

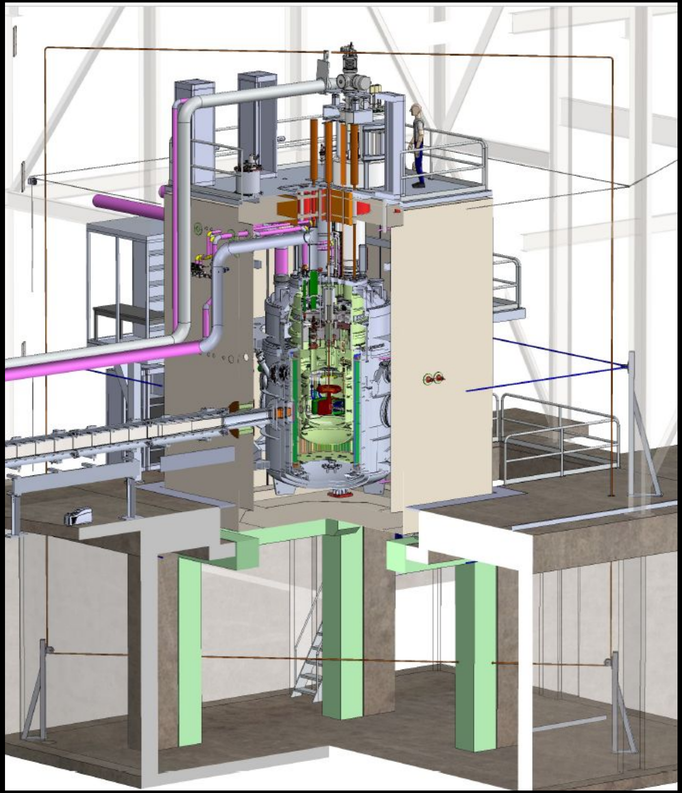
$$n + {}^{3}He \rightarrow p + t + 764\ keV$$

The cross section of the capture is spin dependent

$$S(t) = \frac{\rho_{UCN}\ V}{\tau_{^3He}}(1 - P_n\ P_{^3He} \cdot cos(\theta_{n-^3He}\ t))$$

SOS@PULSTAR and nEDM@SNS


SOS@PULSTAR


nEDM@SNS

SOS@PULSTAR and nEDM@SNS

	Facility	NMR (critical spin dressing)	Polarized 3He	Ultra-cold Neutrons (UCN)	Superfluid helium	dTPB-dPS	LHe Scintillation	SQUIDs	E Field	Huge
nEDM	SNS	y	y	y	y	y	y	y	y	y
SOS	PULSTAR	y	y	y	y	y	y	y	x	x

Takeaways

Systematic and Operational Studies Apparatus (SOS@PULSTAR) is a test bed for nEDM@SNS

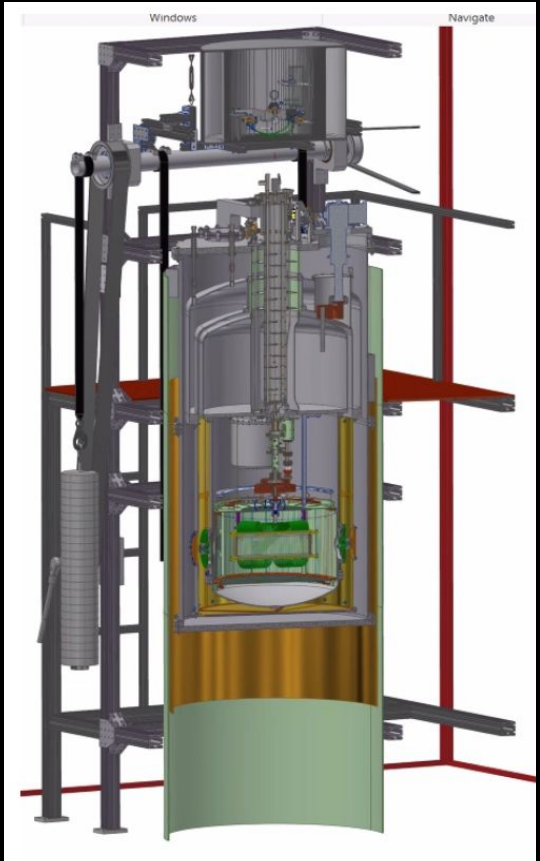
Why?

1. Cooldown cycle for SOS is about 2 weeks.
   Cooldown cycle for nEDM@SNS will take months.
2. Prototype integrated *NMR electronic* + *SQUID* + *Scintillation light* spin manipulation and data acquisition systems
3. Test measurement cells before installation in nEDM@SNS
4. Study geometric phase systematic (3He false EDM)

The main objective is to shorten time-to-data and increase sensitivity for nEDM@SNS

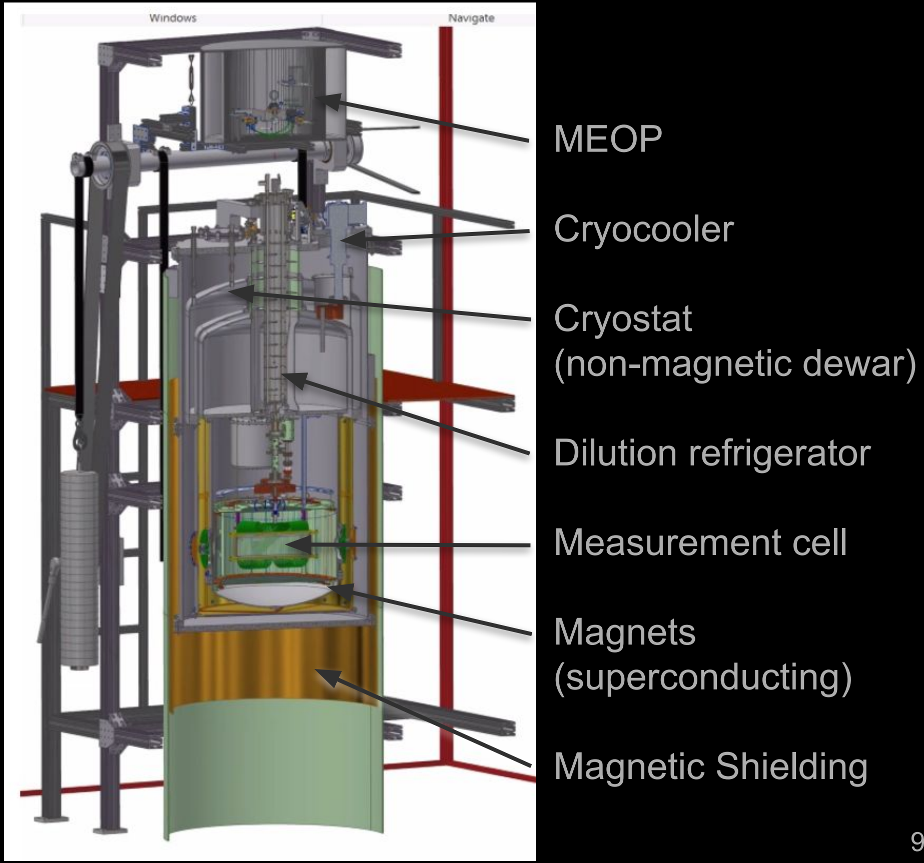
Parameters

- Operate down to 300 mK
- Polarize 3He to 80%
- [3He:4He] concentration as low as 10^{-10}
- Four SQUIDs network with noise down to 0.2-0.25 fT/√Hz
- T2 at least 700 seconds
- UCN density 1 to 10 n/cc

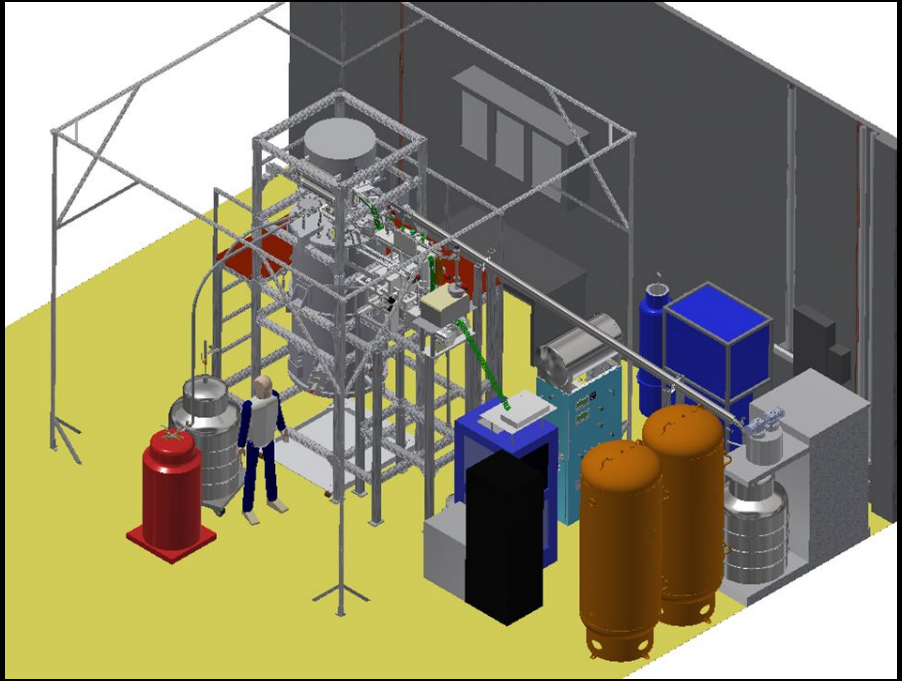


SOS Operation

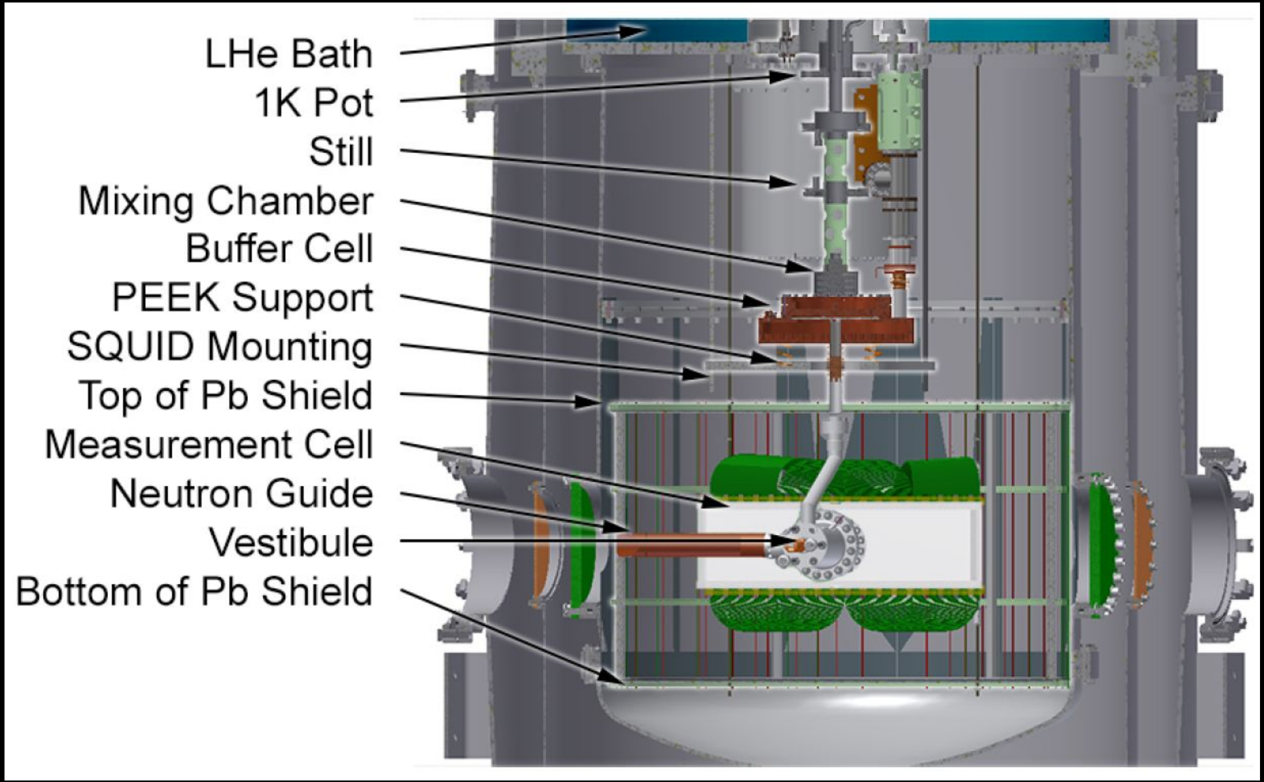
- Polarize 3He using Metability Exchange Optical Pumping (MEOP)
- Polarize neutrons using foils
- Cool volume using dilution refrigerator (DR)
- Measurement cell is 40cm x 3in x 4in
- Manipulate spins using NMR and critical spin dressing
- Measure 3He orientation using SQUIDs
- Detect n-3He interaction events through light collection using SiPMs
- Evacuate 3He using heat flush



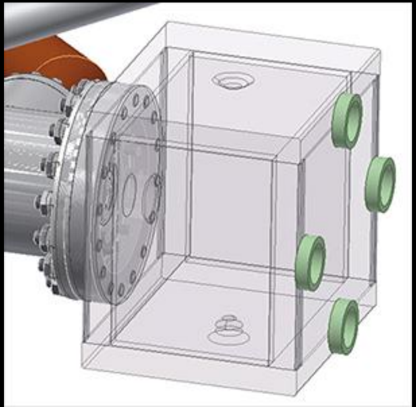
Apparatus

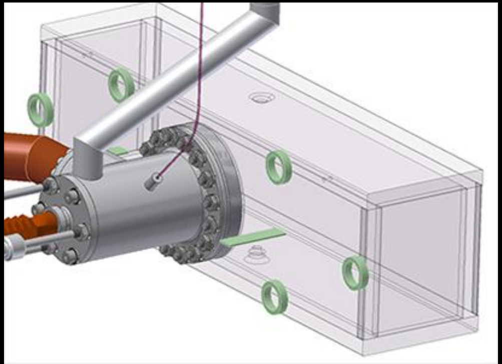


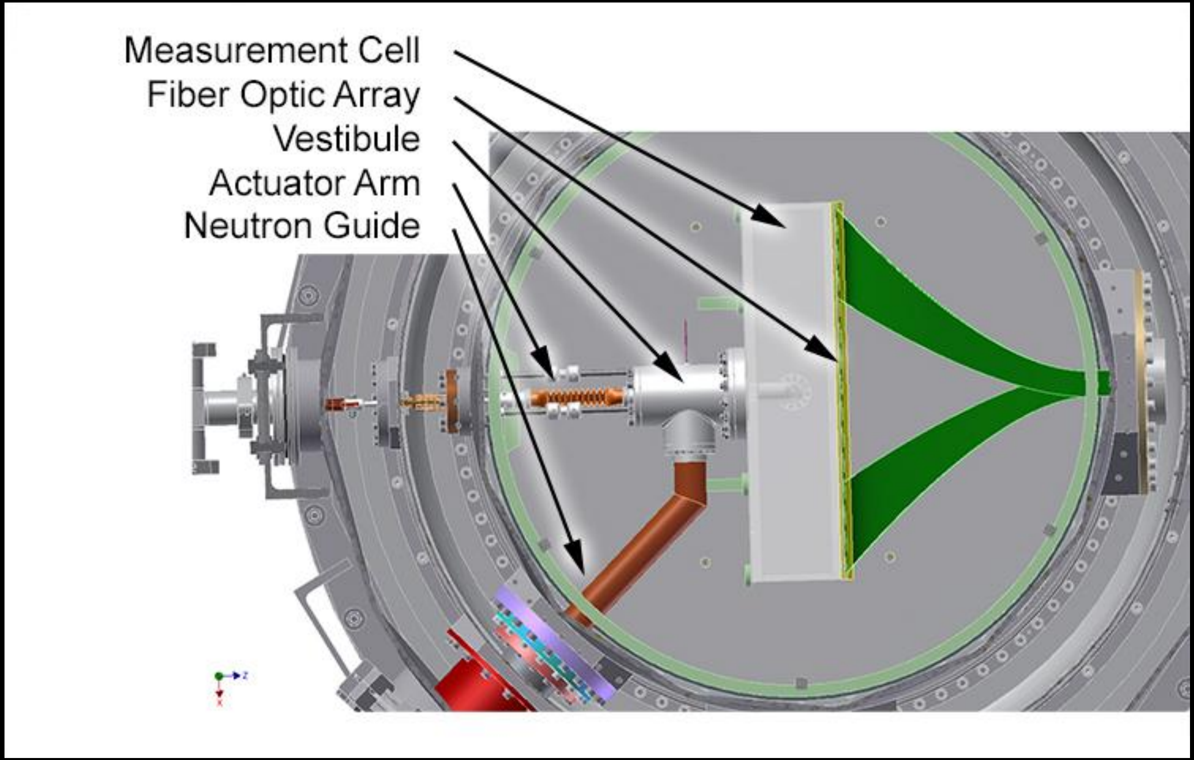
Experimental Region



Experimental Region

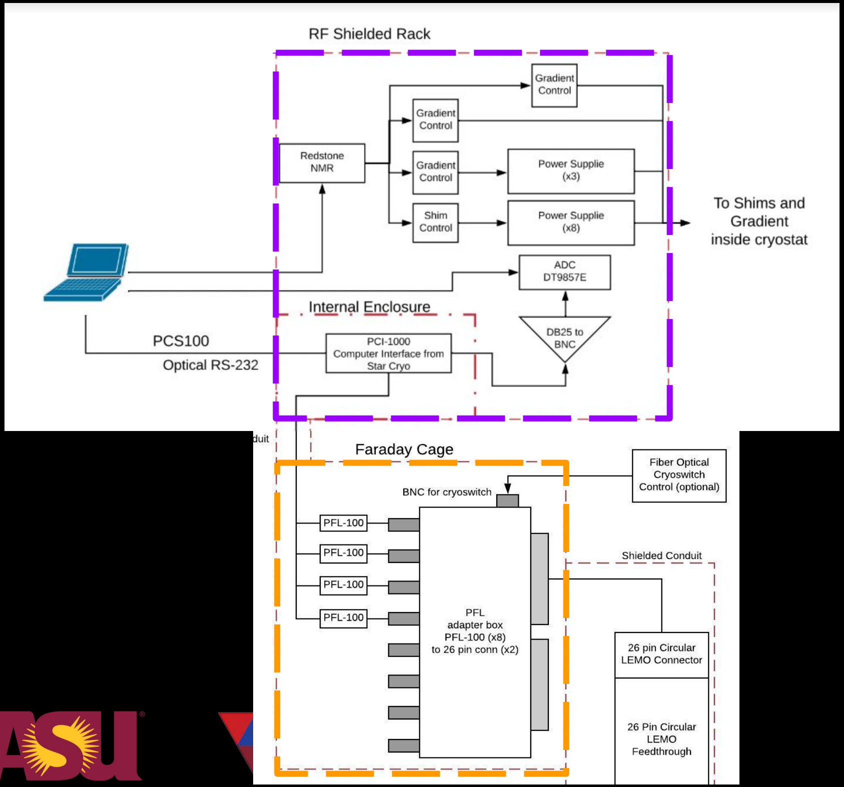




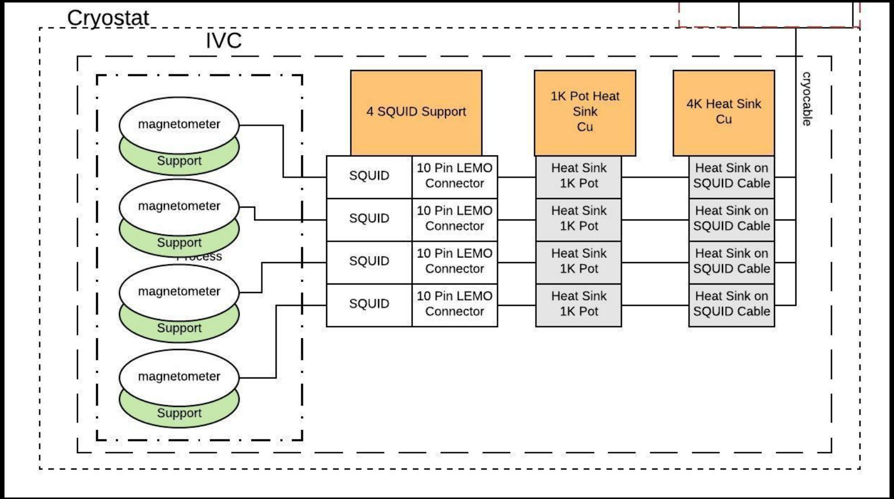


Superconducting QUantum Interference Device System (SQUID)

Room Temp Components



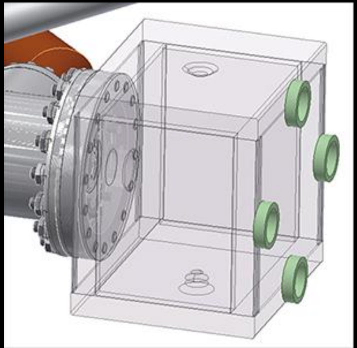
Low Temp Components

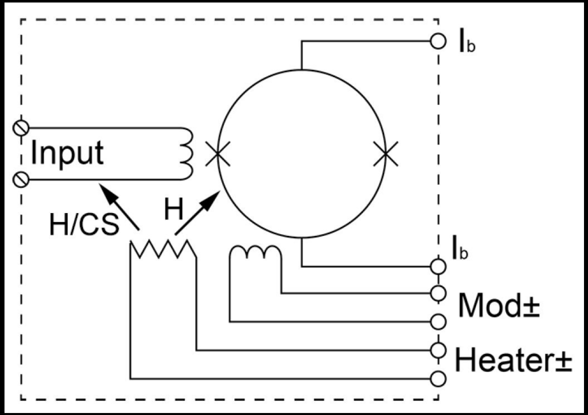


Superconducting QUantum Interference Devices (SQUID)

I have been designing the SQUID system. SQUIDs are used to detect magnetic fields.

When the tipping pulses are applied to the 3He and neutrons, it is possible that a SQUID can become overwhelmed with signal.

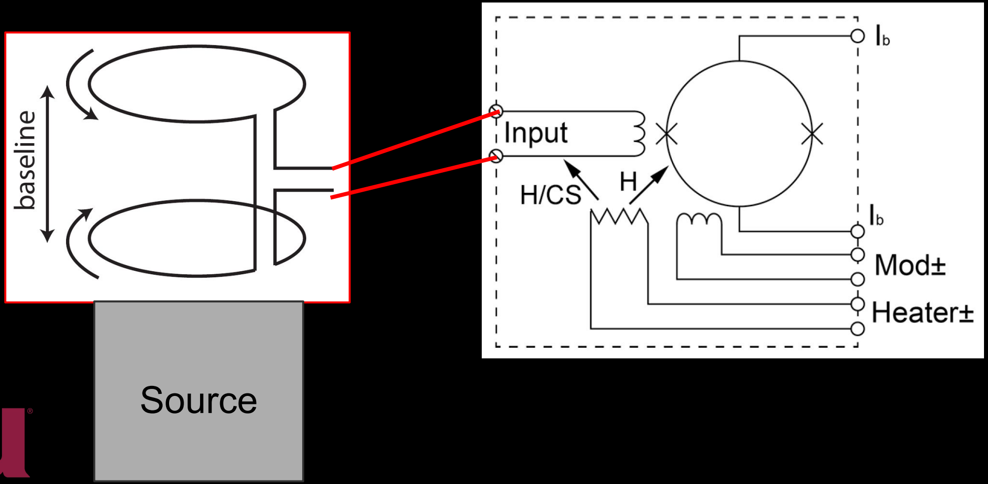




SQUID

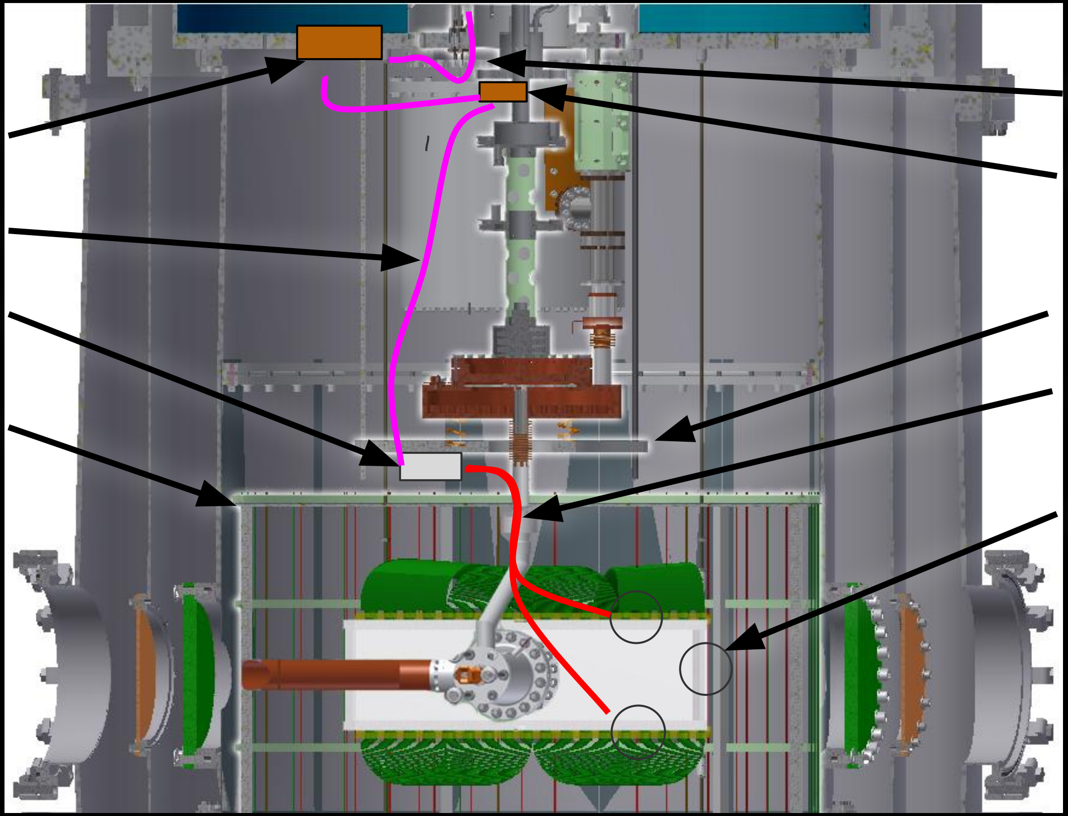
SQUIDs

I’ve been working with Star Cryoelectronics (Santa Fe, NM) to create a new SQUID with an on-board cryoswitch. A cryoswitch allows for short periods of disconnection between the SQUID loop and pickup coils. This switching is controlled through a heat switch on the SQUID chip. It should be able to switch in less than 10 ns.



Example of signal output when using cryoswitch (not Star Cryo SQUID)

SQUIDs


4K Heat Sink
SQUID Cable
SQUID Nb Housing Mount
Pb Shield
SQUID Cable into IVC
1K Pot Heat Sinks (initial testing worked)
PEEK Support
Leads from SQUID to pickup coils
Pickup Coils

Experimental Phases

Phase 1:

The cryostat is currently housed at Duke University in Durham NC. There we will perform geometric phase shift measurements on 3He. We will only be working with superfliud 4He and 3He during this phase.

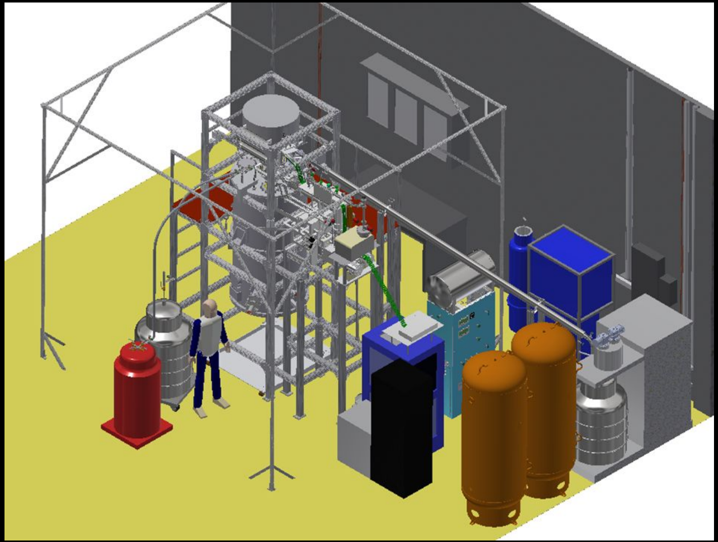
Phase 2:

The cryostat will be moved to the PULSTAR research reactor at NC State University. There we will introduce UCN and 3He to measurement cell. This will be the first time UCN and 3He are studied in the same vessel.

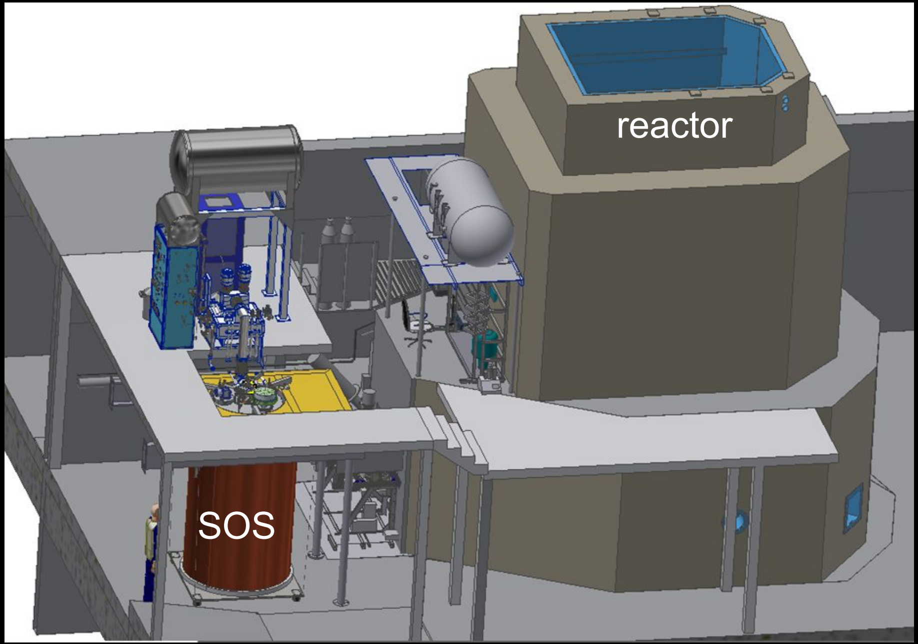
Experimental Phases

Phase 2: Future location

Phase 1: Current location



SOS@TUNL on Duke Campus



SOS@PULSTAR on NCSU Campus

Current Status

Fully commissioned and operational

- MEOP
- dewar with DR and cryocooler
- buffer cell

Operational

- NMR/ADC/internal clock
- SQUIDs

Assembly and fabrication

- MEOP assembly
- External magnetic coils
- Charcoal pump
- Magnetic shield
- Measurement cell
- Actuator

Currently being tested

- SQUID with cryoswitch
- Persistence switch (B0 coil)
- SC leads (RF coil)
- Noise for SQUID electronics

Mechanical design in progress

- SC shield
- B0 coils
- RF coils

Other speakers about SOS during this conference

- Christian White
  - Design, testing, and characterization of the helium-3 removal system
- Thomas Rao
  - 3He Polarization and Injection System for the nEDM@SNS SOS apparatus - MEOP
- Matthew Morano
  - Superconducting QUantum Interference Devices (SQUIDs) for magnetic field detection : noise measurements
- Clark Hickman
  - Creation of a superconducting switch to close the B0 coil in the nEDM@SNS experiment
- Cole Teander & Clark Hickman
  - Classical Derivation of Frequency Shifts and Berry's Phase
- Chris Swank
  - Systematic effects studies at the Systematic and Operational Studies apparatus (SOS@PULSTAR)

- As well as a lot of talks about nEDM@SNS which are very related

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People

Institutions

nEDM @SNS

Robert Golub[1]
Katerina Korobkina[1]
Paul Huffman[1]
R. Adam Dipert[2]
Igor Berkutov[1]
Thomas Rao[1]
Matthew Morano[1]
Cole Teander[1]
Austin Reid[8]
Steven Clayton[5]
Kent Leung[9]

Christian White[1]
Clark Hickman[1]
Vince Cianciolo[4]
Libertad Barrón Palos[6]
Brad Filippone[3]
Wolfgang Korsch[7]
Christopher Swank[3]
Ricardo Alarcon[1]

And many others...

[1]North Carolina State University
[2]Arizona State University
[3]California Institute of Technology
[4]Oak Ridge National Laboratory
[5]Los Alamos National Laboratory
[6]Universidad Nacional Autónoma de México
[7]University of Kentucky
[8]Indiana University
[9]Duke University
Triangle Universities Nuclear Laboratories

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End

R. Adam Dipert - rdipert@asu.edu

R. Adam Dipert
Arizona State University