Progress Overview of nEDM@SNS

E. Korobkina

on behalf of

nEDM@SNS collaboration

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[b] *Department of Physics, Duke University, Durham, NC 27708, U.S.A.*

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[f] *Physics Department, University of Virginia, 382 McCormick Road, Charlottesville, VA 22904, U.S.A.*

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[h] *Instituto de Física, Universidad Nacional Autónoma de México, Apartado Postal 20-364, 01000, Mexico*

[i] *Bartoszek Engineering, 818 W. Downer Place, Aurora, IL 60506-4904, U.S.A.*

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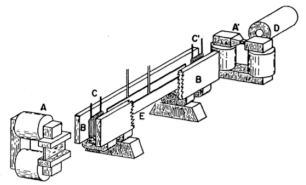
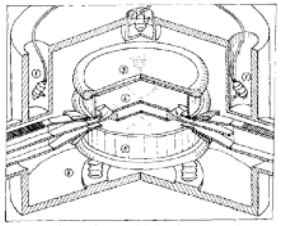
MILESTONES OF NEDM EXPERIMENTAL TECHNIQUE

- **Neutron beam nEDM technique:**
  - **n**EDM upper limit from $d_n=(—0.1 \pm 2.4)\times10^{-20}$ down to $d_n=(+0.4 \pm 1.5)\times10^{-24}$
  - Further progress was troubled mainly by *systematic* linear **E** x **v/c** effect related to $B_0 \uparrow E$ alignment



- **switch to UCN nEDM technique:**
  - gain by dramatic increase of observation time from milliseconds to 50s.
  - elimination of linear systematic **E** x **v/c** effect due to <**v**>=0 (randomized UCN movement)
  - nEDM upper limit $d_n<2.6\times10^{-25}$
  - Further progress was troubled by statistic and *systematic* of magnetic field instability



- **addition of co-magnetometer to UCN nEDM technique ('traditional technique'):**
  - nEDM upper limit $d_n<2.9\times10^{-26}$
  - Further progress is troubled mainly by *systematic* arising from B_m=**E** x **v/c** interaction with stray B_0 field gradients; effect is dominated by contribution from co-magnetometer atoms

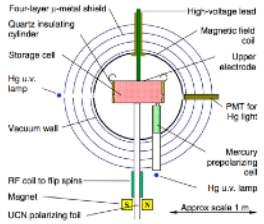


FIG. 1 (color online). Experimental apparatus.

- **present nEDM projects in progress (traditional technique) :**
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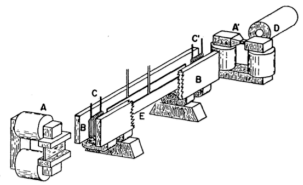

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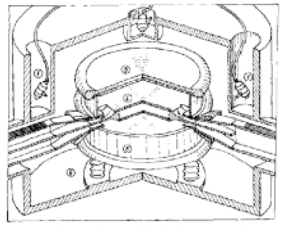

- **addition of co-magnetometer to UCN nEDM technique ('traditional technique'):**
  - nEDM upper limit $d_n = (0.0 \pm 1.1_{\text{stat}} \pm 0.2_{\text{sys}}) \times 10^{-26} e.\,\text{cm}.$
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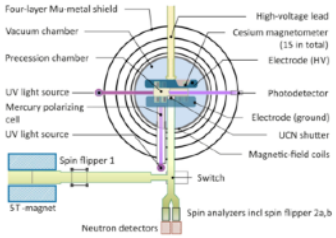

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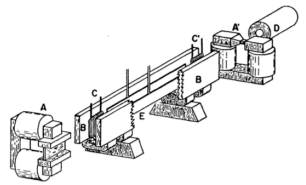

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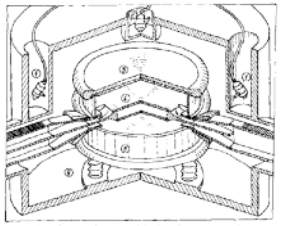

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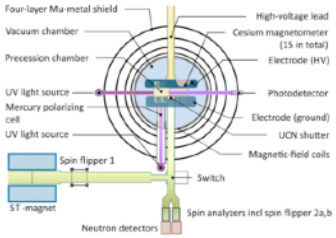

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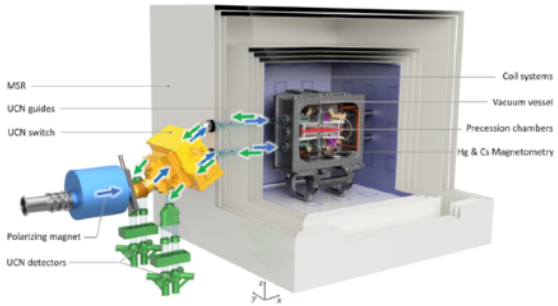

COMPARISON OF TWO TECHNIQUES

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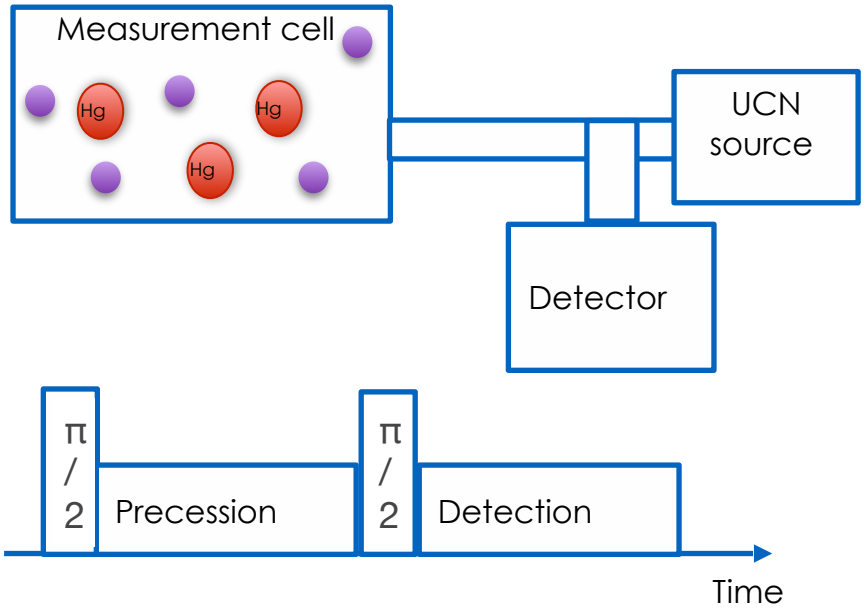

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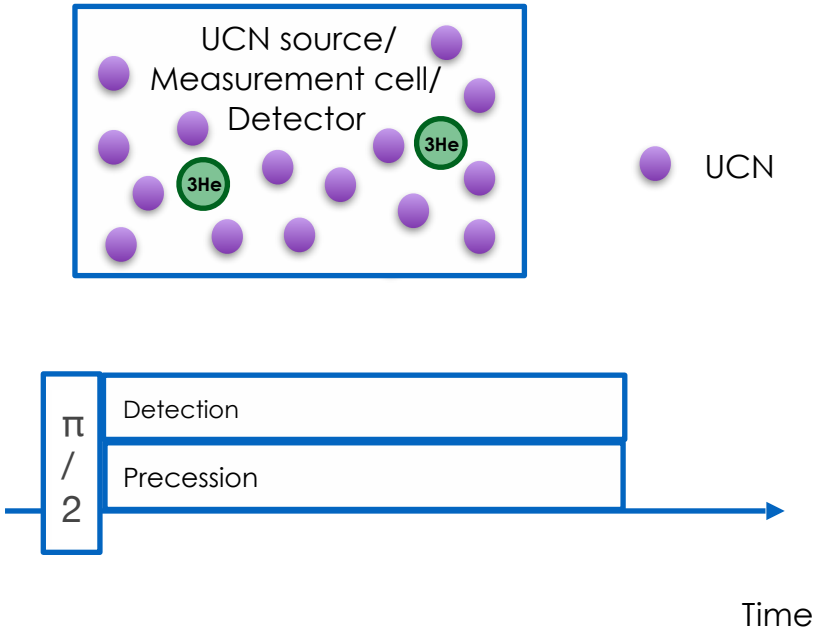

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R. Golub & S. K. Lamoreaux, Phys. Rep. 237, 1 (1994)

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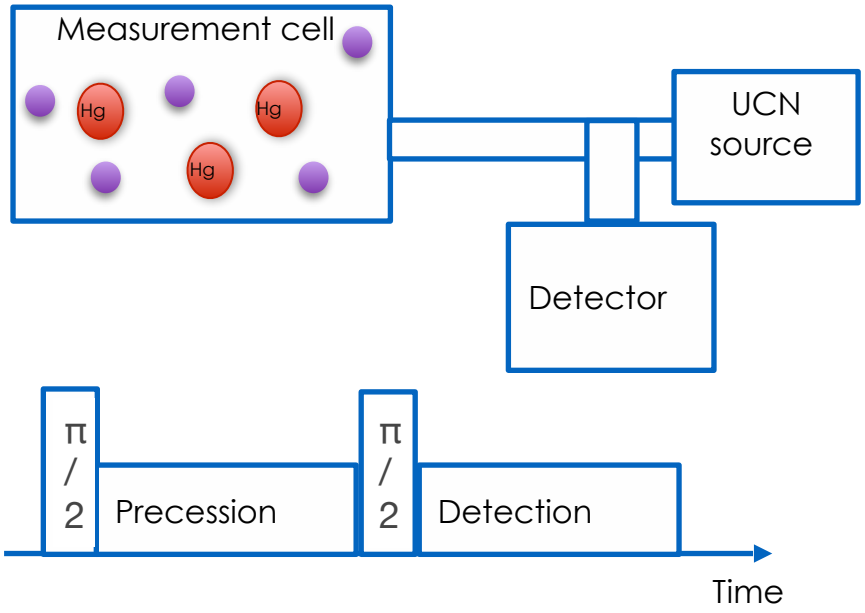

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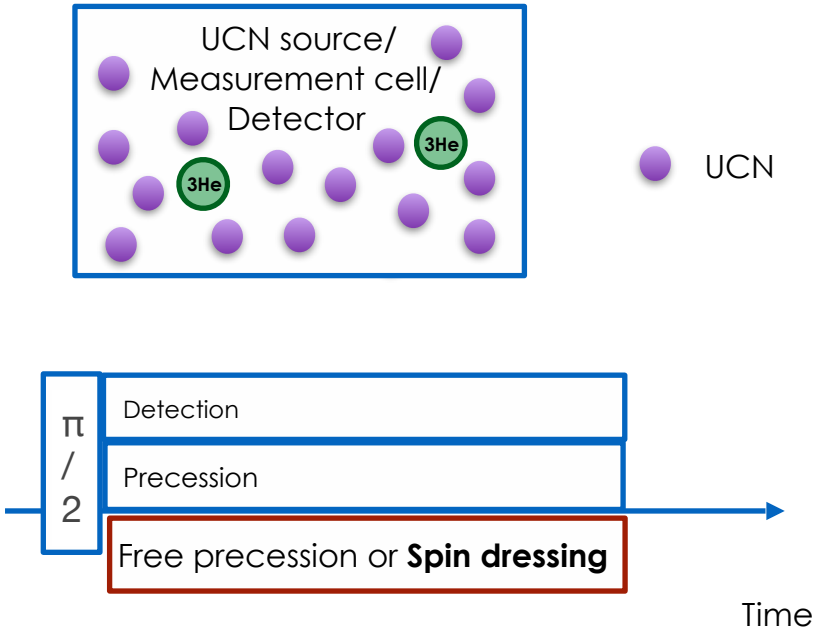

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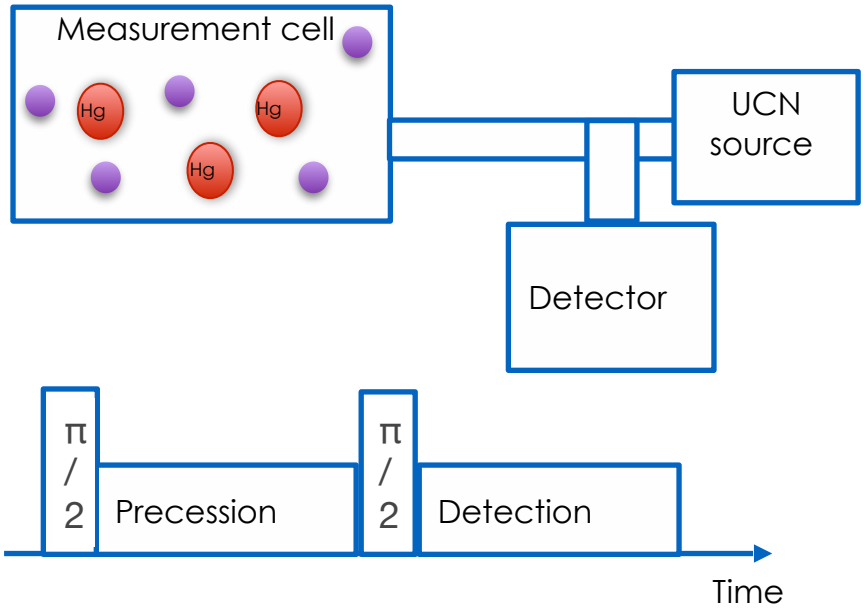

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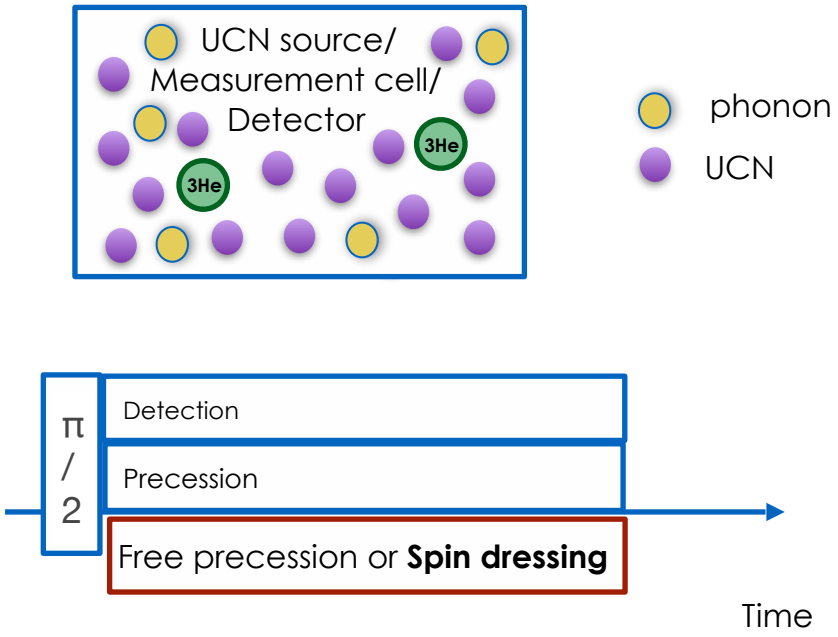

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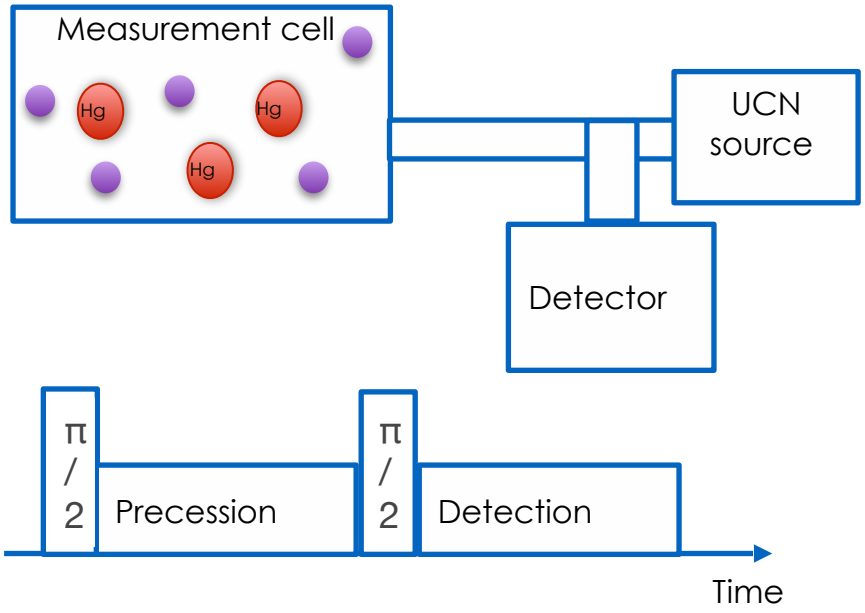

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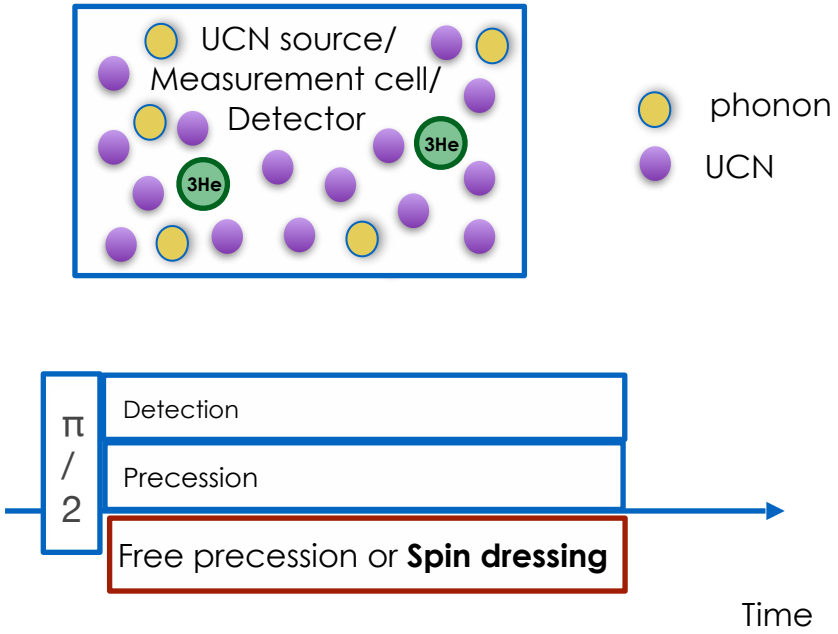

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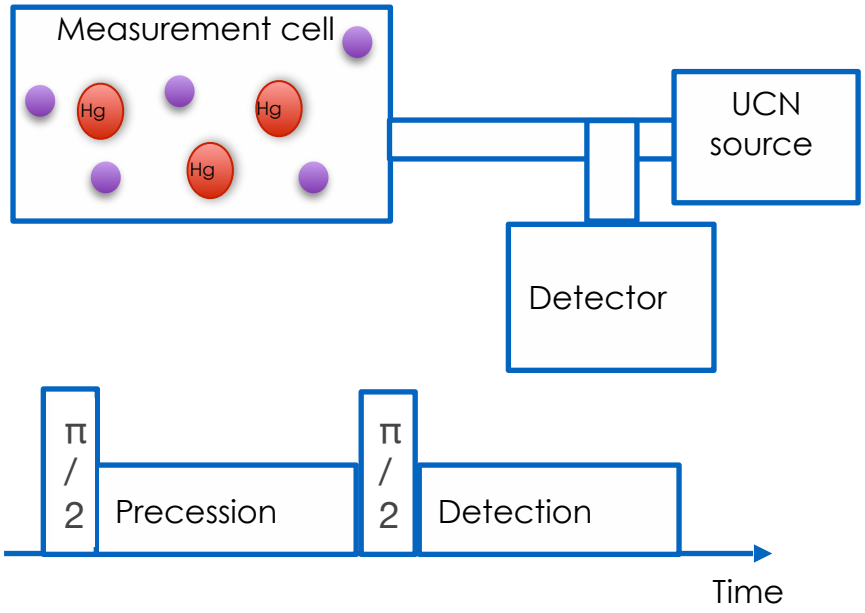

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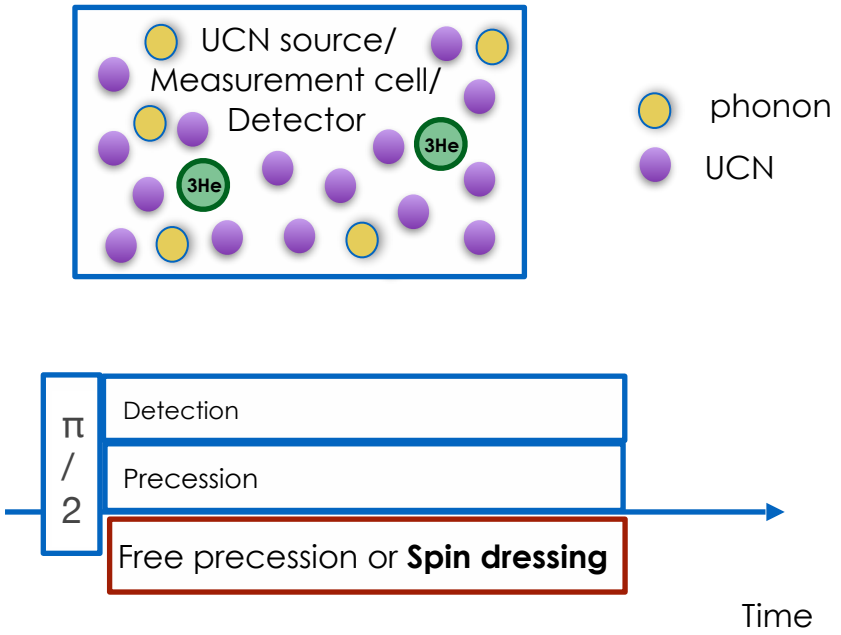

- Pro:
  - increase in statistical sensitivity
  - suppression of main systematic well below 10^{-28}
- Con: extreme engineering and scientific challenges

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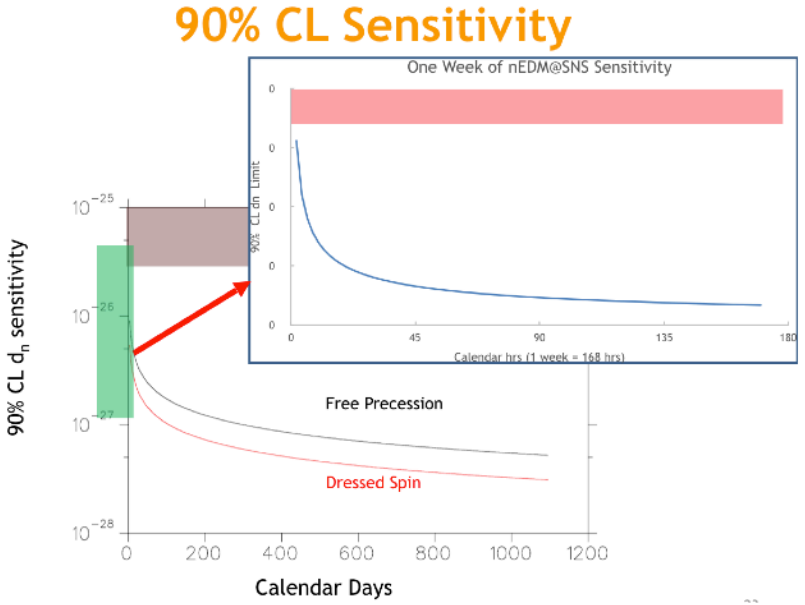
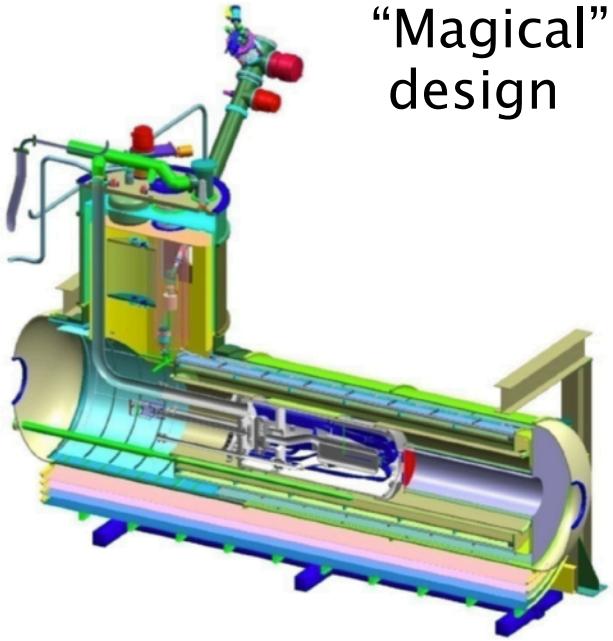
R. Golub & S. K. Lamoreaux, Phys. Rep. 237, 1 (1994)

NEDM EXPERIMENT @SNS

- High trapped neutron densities
- LHe as HV insulator (> 7x Vacuum HV)
- Use of a ^{3}He co-magnetometer and superconducting shield
- Variation of LHe temperature to study v x E systematics
- Precession frequency measurement via two techniques
- Sensitivity reach: **d_n < 3 x 10^{-28} e-cm (in 3 calendar yrs)**



HOW OUR PROJECT STARTED?



"Magical" engineering design

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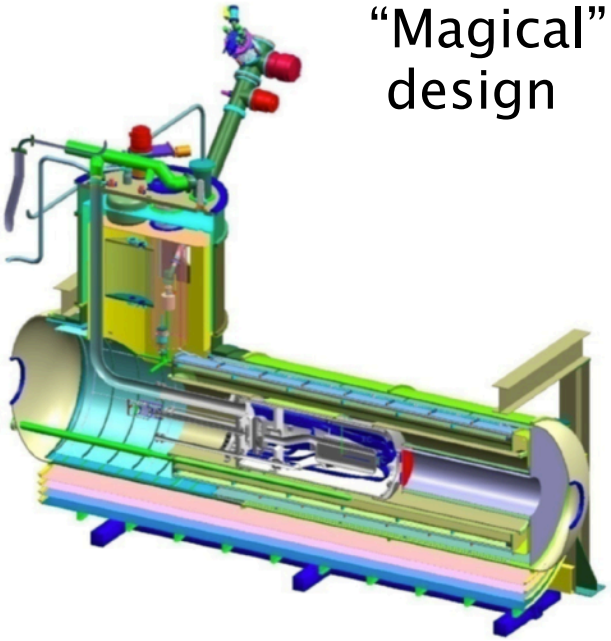

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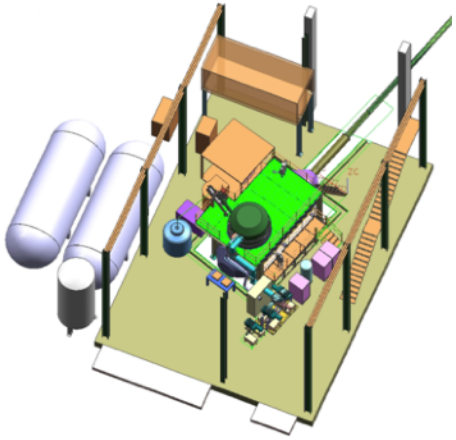

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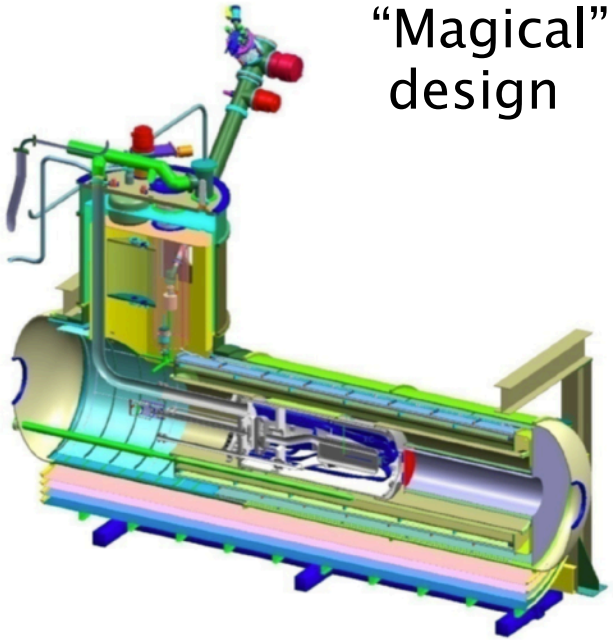

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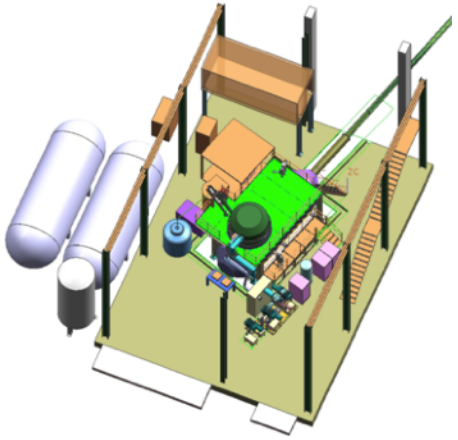


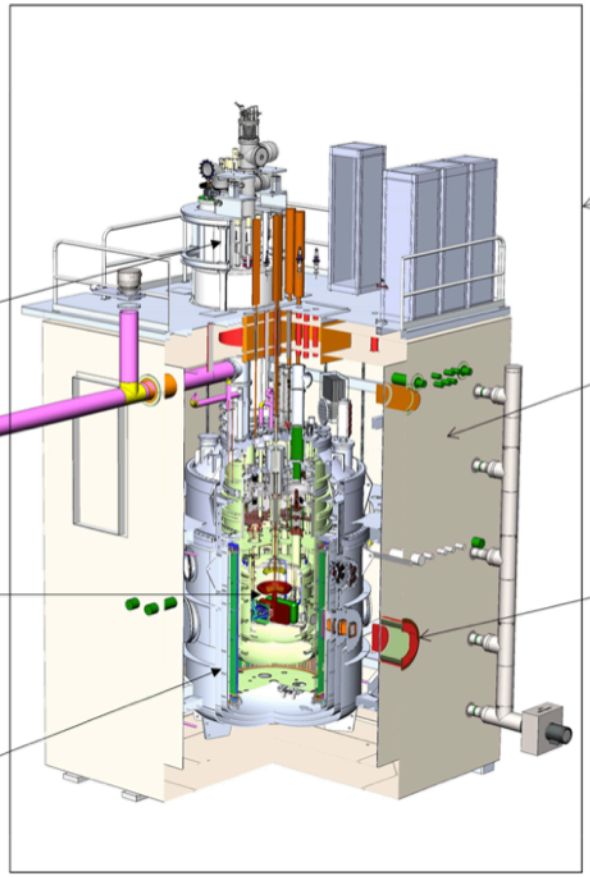
NEDM@SNS EXPERIMENT IN 2021

Experiment Design

Helium-3 Services
- Prepare polarized 3He
- Isotopically purify 4He each measurement cycle

Central Detector System
- Generate electric field
- Store 3He, neutrons
- Monitor 3He, neutron precession frequencies

Magnet Coil Package
- Inner magnetic shielding
- Generate uniform B-field

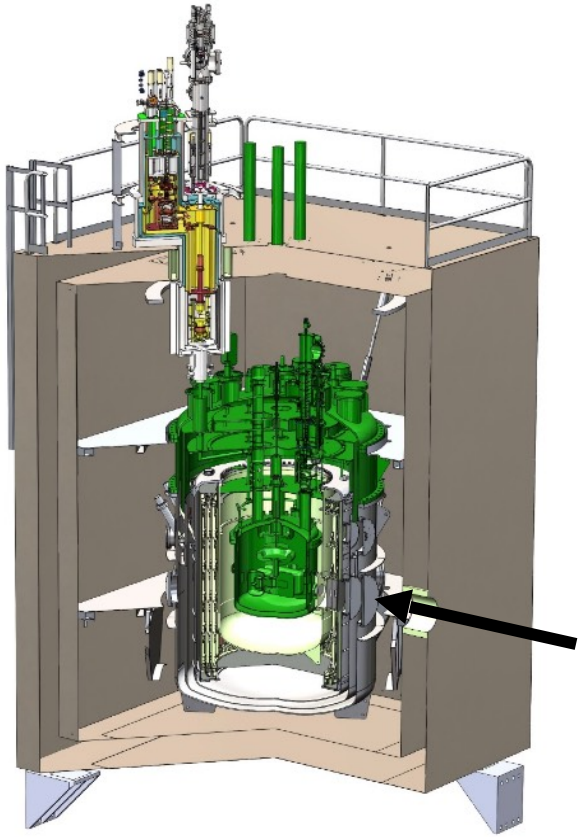


Outer magnetic shielding
Cancellation coils

Magnetically Shielded Enclosure

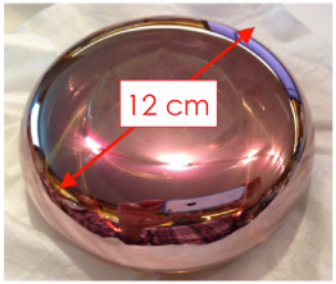
Guide 8.9Å into apparatus

CENTRAL DETECTOR SYSTEM (CDS)



CDS includes:

- HV System: goal 70kV/cm inside the measurement cells
- Measurement Cells
- Non-Mag Dilution Fridge
- SQUID System
- Light Collection System



PMMA electrode with Cu implantation for MSHV. E> 85 kV/cm achieved.

CDS progress status:

- **Non-Mag Dilution Fridge** - fabrication in progress
- **SQUID System** - R&D completed, currently setting up for a test of SQUID magnetometer prototypes
- **Light Collection System** - R&D, design and prototype testing have been completed
- **Measurement Cells** - continue development and testing of PMMA cells
- **HV System:**
  - continue R&D of breakdowns using stainless steel electrodes and plastic electrodes
  - prototype testing of Cavallo multiplier

CDS R&D: HIGH VOLTAGE STUDY TESTS

Small Scale High Voltage (SSHV) cryostat is used to study breakdowns with small electrodes.

At present it is fully assembled with mechanically-polished (MP) stainless steel electrodes installed :

- Field emission measurements in vacuum at room temperature to help characterize electrodes before cooldowns.
- Replace MP electrodes for electropolished & PMMA coated ones & repeat measurements.
- LHe breakdown measurements with MP/EP hybrid electrodes & PMMA electrodes.

A study of DC electrical breakdown in liquid helium through analysis of the empirical breakdown field distributions

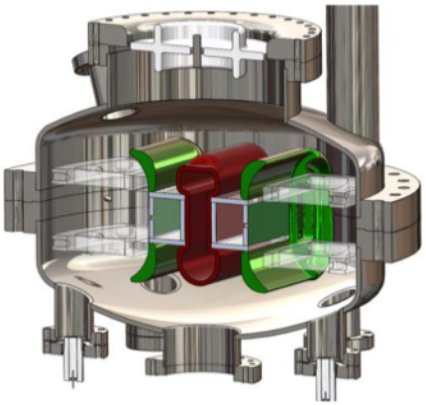
N. S. Phan,[1,2] W. Wei,[1] B. Beaumont,[2] N. Bouman,[3] S. M. Clayton,[1] S. A. Currie,[1] T. M. Ito,[1,3] J. C. Ramsey,[1] and G. M. Seidel[2,3]
[1] *Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[2] *Department of Physics, North Carolina State University, Raleigh, NC 27695*
[3] *Department of Physics and Astronomy, Valparaiso University, Valparaiso, IN 46383*
[4] *Department of Physics, Brown University, Providence, Rhode Island 02912*

(Dated: 19 November 2020)

We report results from a study on electrical breakdown in liquid helium using near-uniform-field stainless steel electrodes with a stressed area of ~0.725 cm^2. The distribution of the breakdown field is obtained for temperatures between 1.7 K and 4.0 K, pressures between the saturated vapor pressure and 626 Torr, and with electrodes of different surface polishes. A data-based approach for determining the electrode-surface-area scaling of the breakdown field is presented. The dependence of the breakdown probability on the field strength as extracted from the breakdown field distribution data is used to show that breakdown is a surface phenomenon closely correlated with Fowler-Nordheim field emission from asperities on the cathode. We show that the results from this analysis provides an explanation for the supposed electrode gap-size effect and also allows for a determination of the breakdown-field distribution for arbitrary shaped electrodes. Most importantly, the analysis method presented in this work can be extended to other noble liquids to explore the dependencies for electrical breakdown in those media.

Half Scale High Voltage (HSHV) cryostat is designed to study breakdowns with half-scale of real electrodes to understand better scaling of breakdowns and dependence on temperature and pressure.

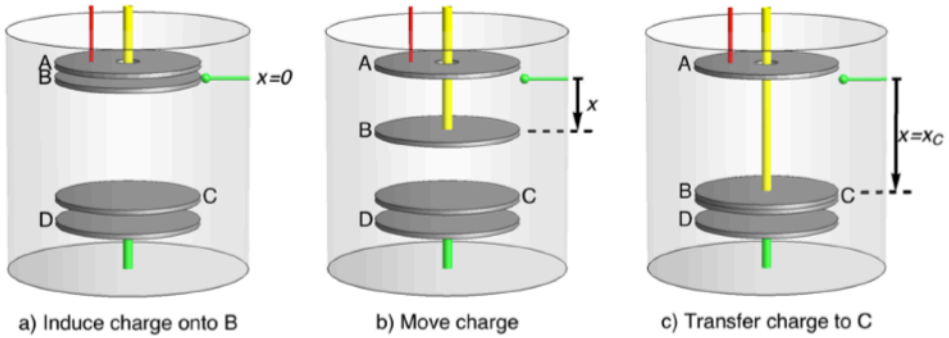
The commissioning cool down (without HV feedthrough and electrodes) was successful in Dec 2020, now system is in preparation for the first HV test scheduled in July 2021 .

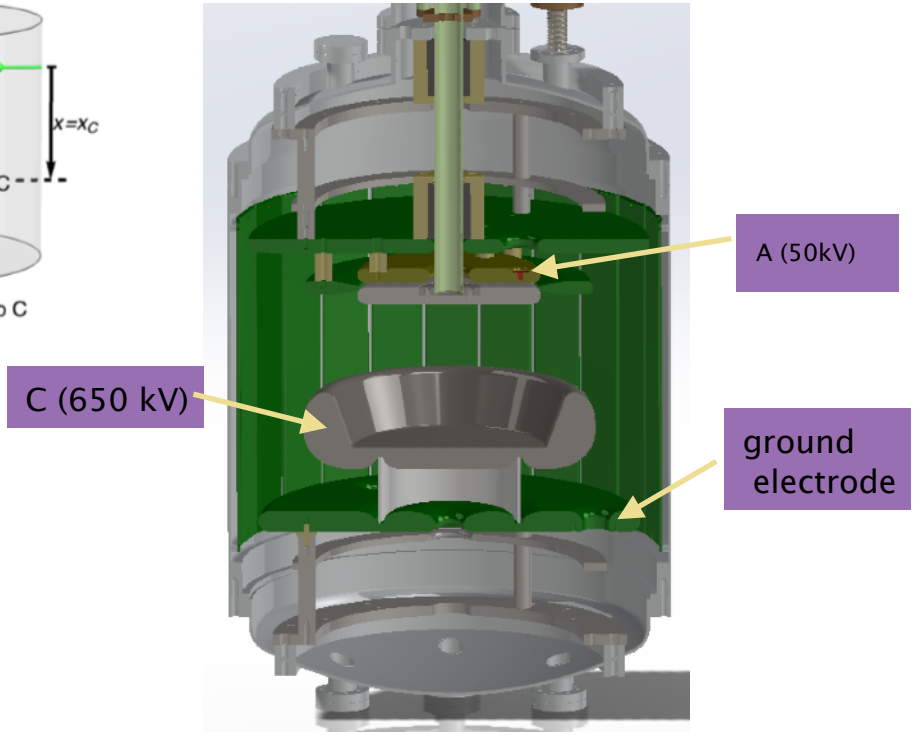


1/2 scale measurement cell electrodes

CDS R&D: CAVALLO VOLTAGE MULTIPLIER

Cavallo Voltage Multiplier will be used to reach ultimate high voltage specifications without development of a custom cryogenic feedthroughs.

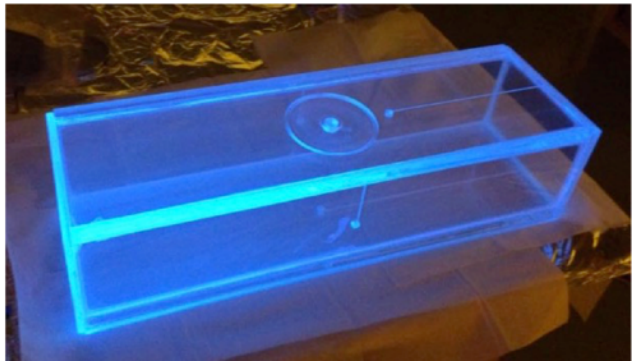


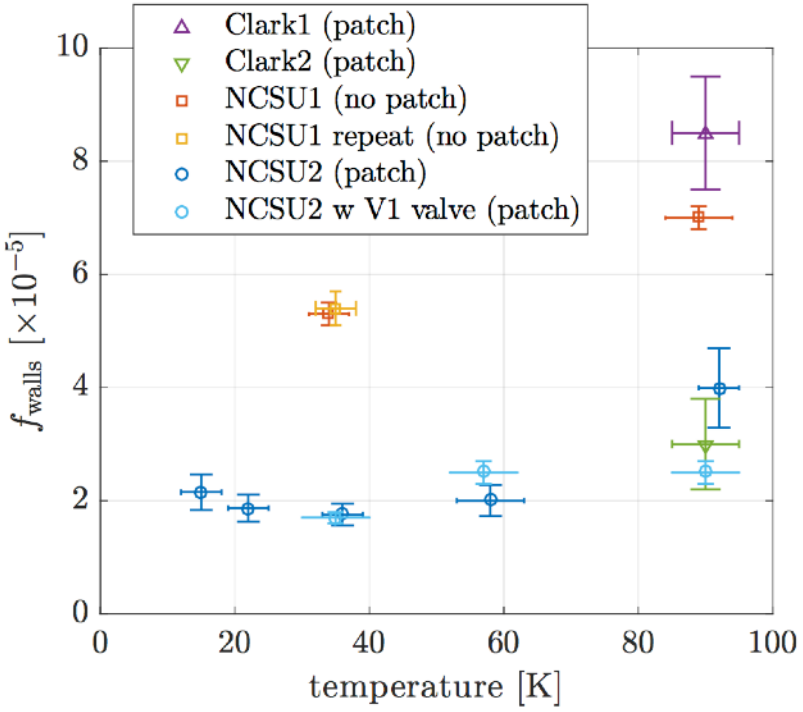


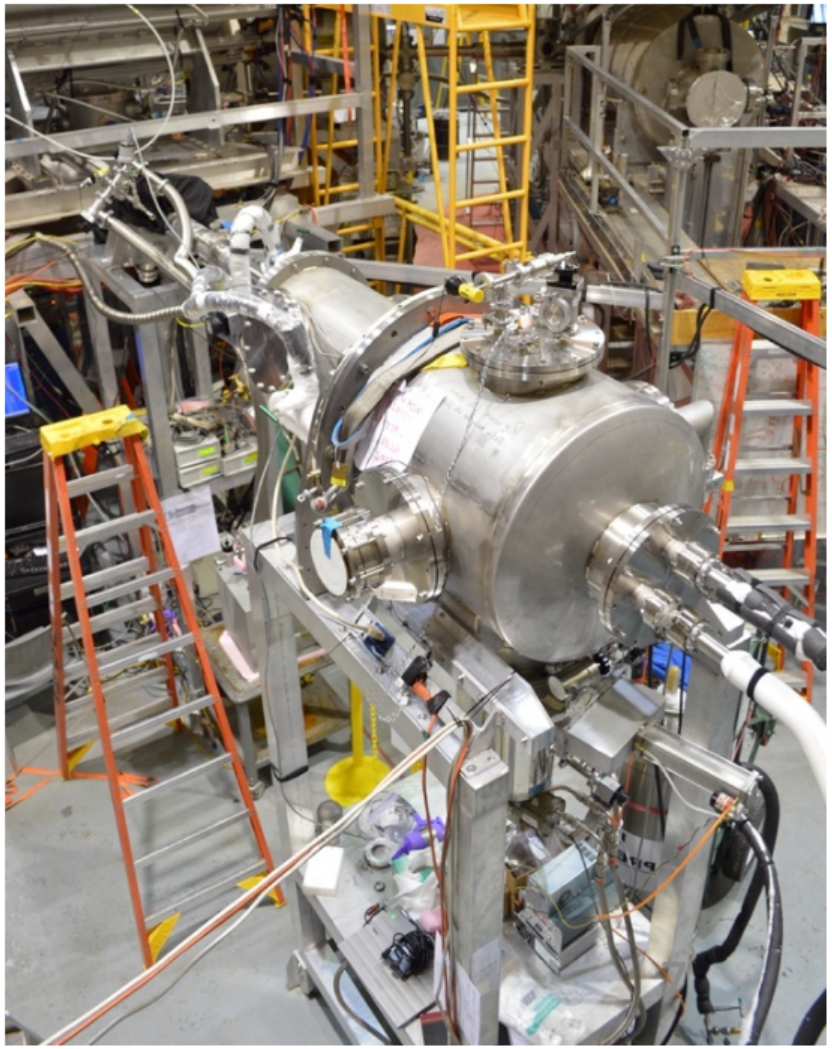
At present components the Cavallo test-bed are being fabricated:

- we have a cryogenic dewar
- A,B, C and ground ring electrodes are ready to be sent for polishing
- Engineering on the actuator cold bellows and the refrigerator components of the test-bed are in progress.

CELL CHARACTERIZATION

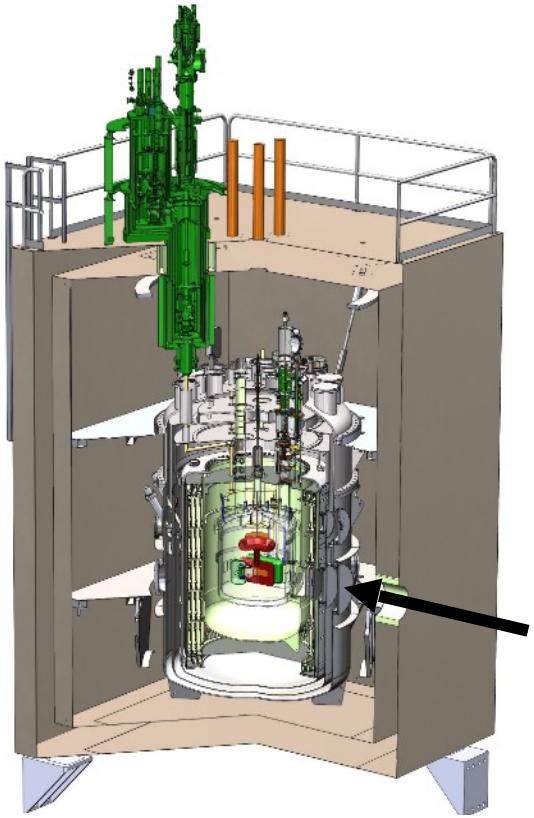






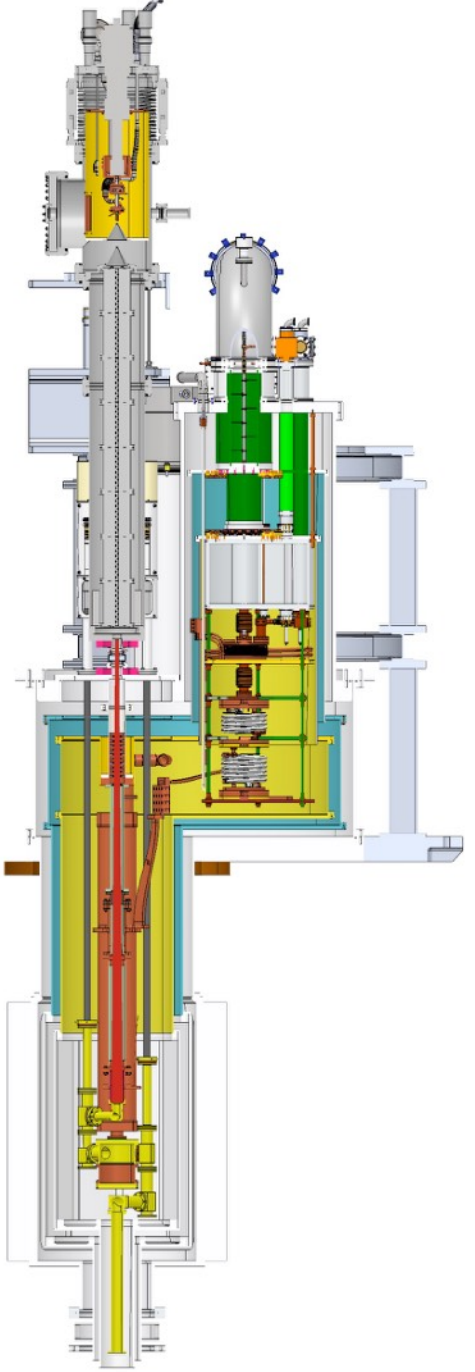
Experimental set-up at LANL UCN source

POLARIZED ^{3}HE SYSTEM

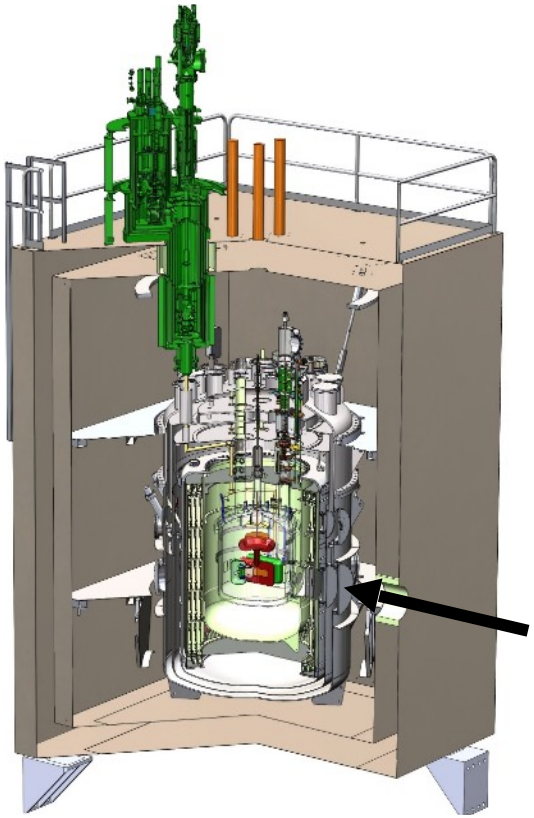


Components:

- Non-Magnetic Dilution Fridge (DR) 80 mW power
- Injection Module
- ^{3}He Spin Transport
- Heat Flush
- Atomic Beam Source (ABS)
-



POLARIZED ^{3}HE SYSTEM



Components:

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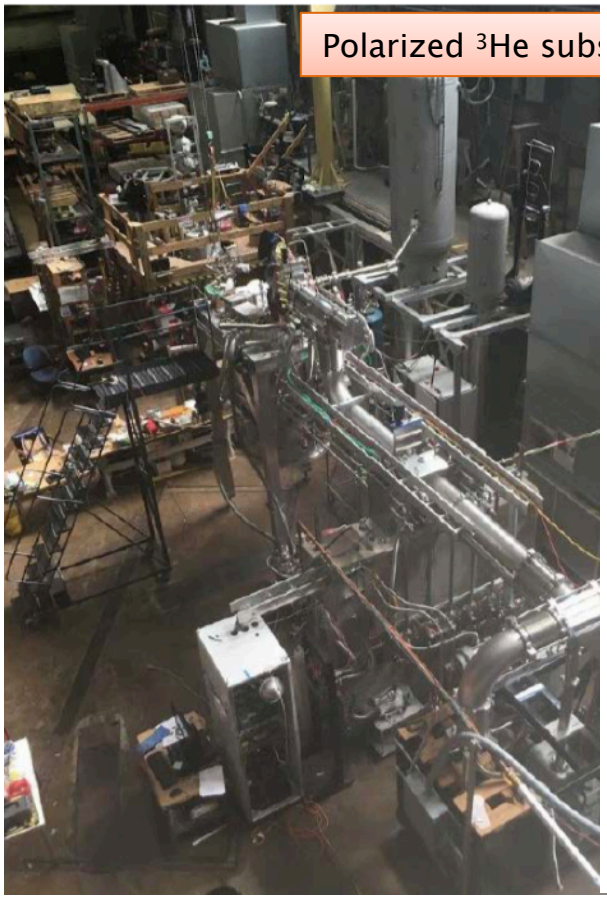
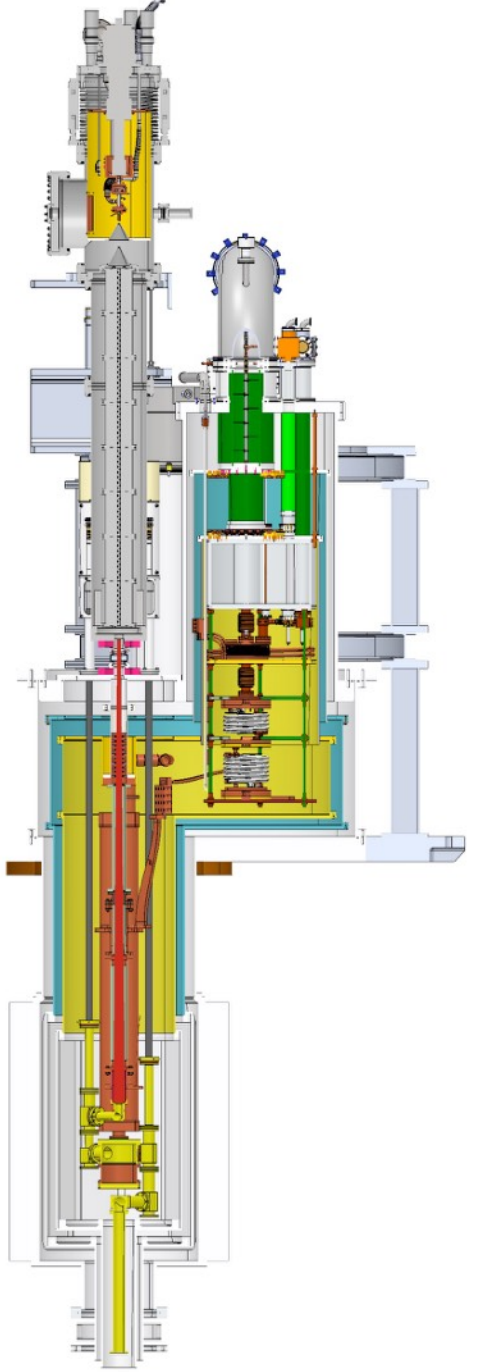
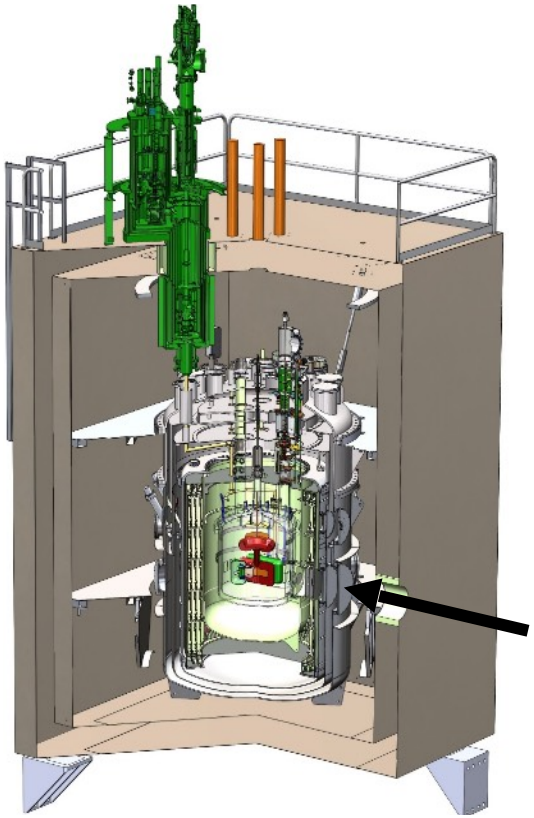
- Heat Flush
- Atomic Beam Source (ABS)
-



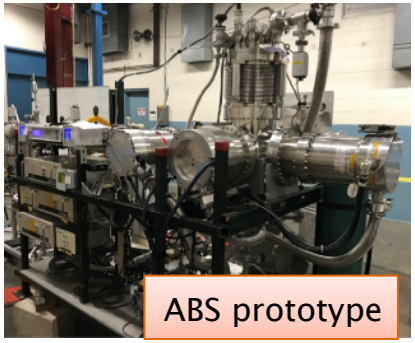


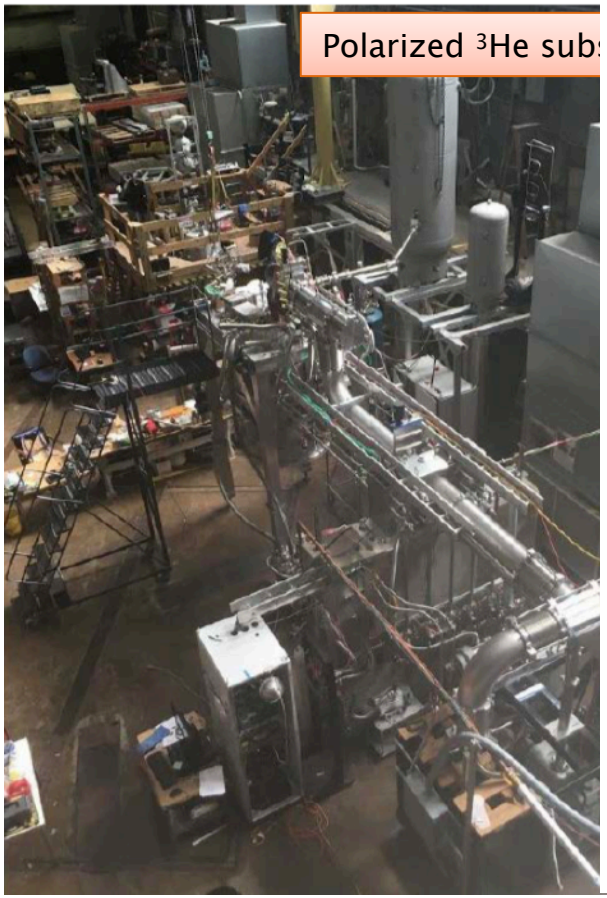
POLARIZED ^{3}HE SYSTEM

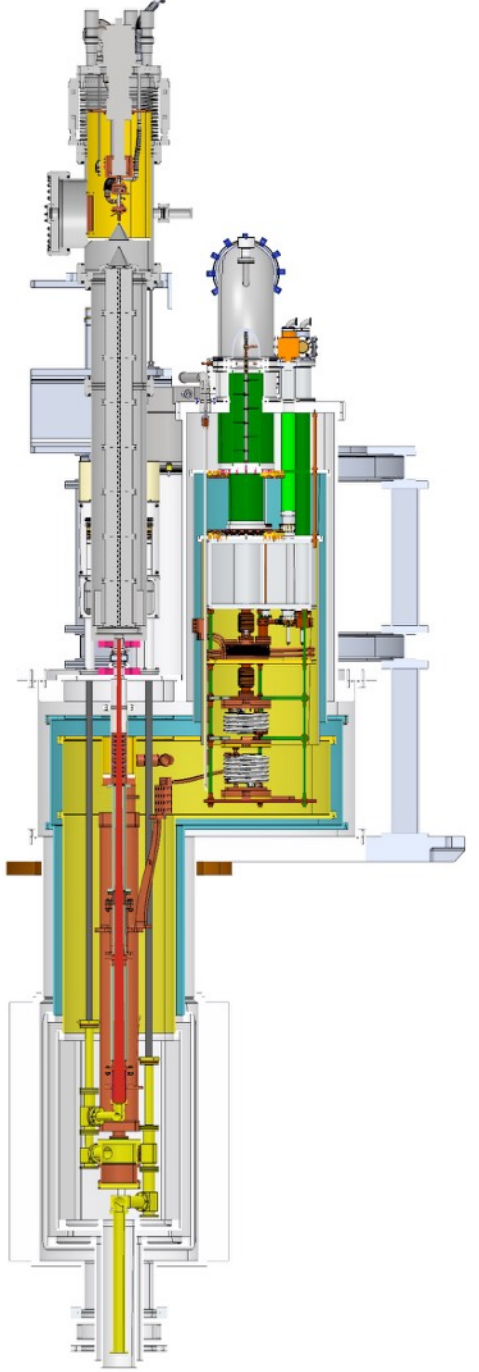


Components:

- Non-Magnetic Dilution Fridge (DR) 80 mW power
- Injection Module
- ^{3}He Spin Transport
- Heat Flush
- Atomic Beam Source (ABS)
-

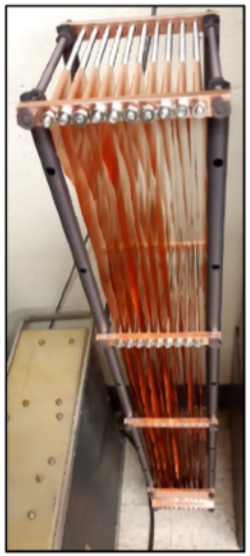

ABS prototype


Polarized ^{3}He subs

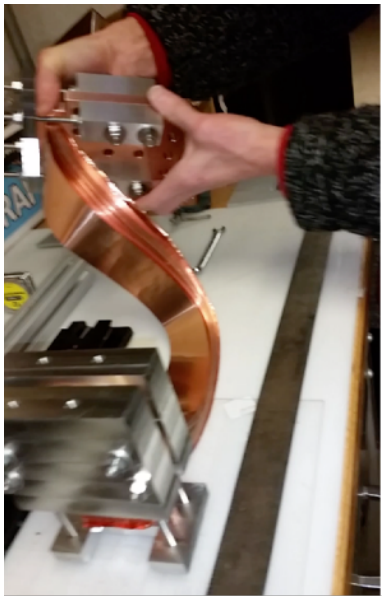


POLARIZED ^{3}HE SYSTEM

Non-magnetic DR insert

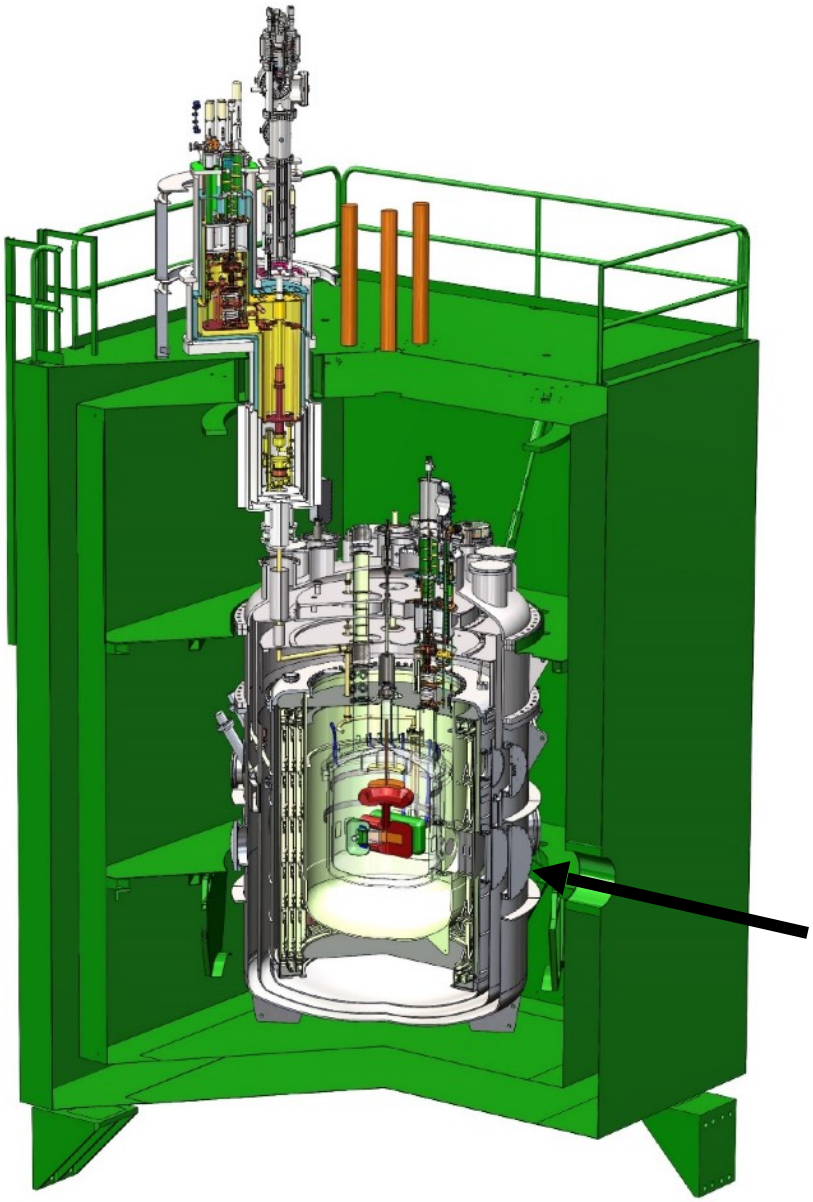


Molybdenum rack half-loaded with copper foils in preparation for heat treatment for high thermal conductivity.



Setup for pressure-forming seamless Kapton tubing during bonding to the interior of the injection volume

ROOM TEMP. MAGNETIC SHIELD ENCLOSURE (MSE)



MSE includes:

- 2-layers mu-metal shielded house
- External Field Compensation Coils
- Inner Shield Coil
- Support structure for the cryostat

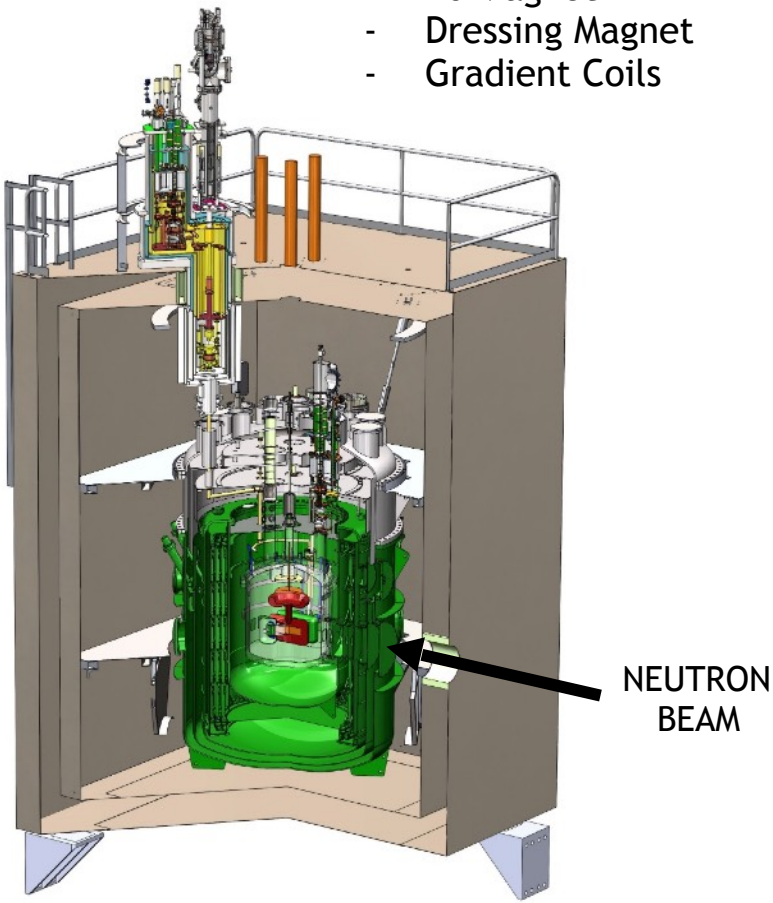
Status:

- ordered, fabrication in progress

CRYOGENIC MAGNET SYSTEM

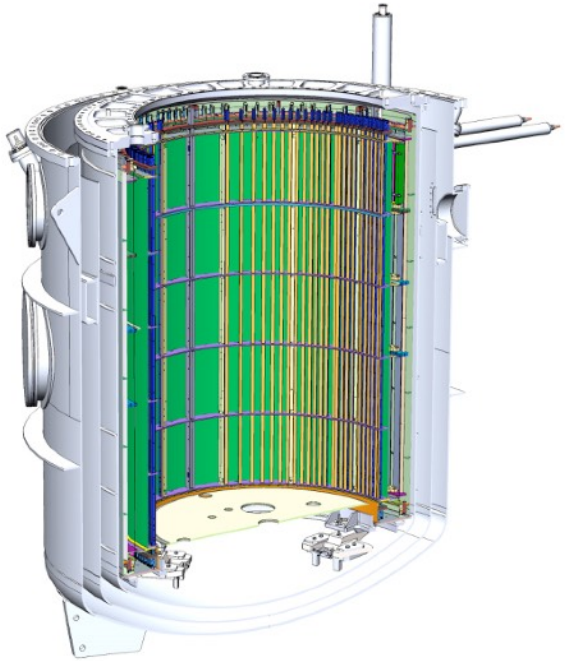
Cryogenic Magnet System components:

- 4K shield for CDS
- Pb Superconducting Shield
- B0 Magnet
- Dressing Magnet
- Gradient Coils

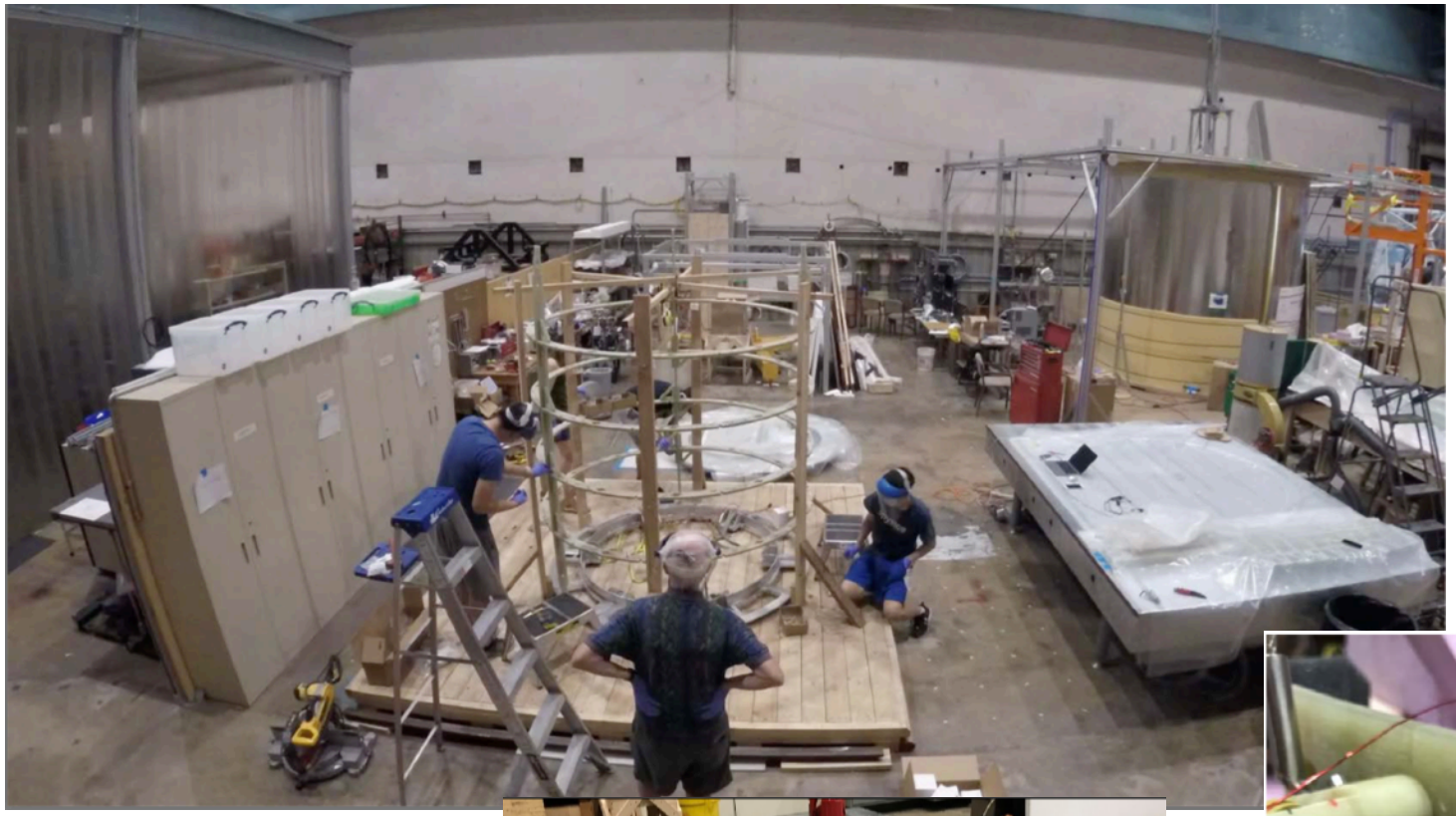


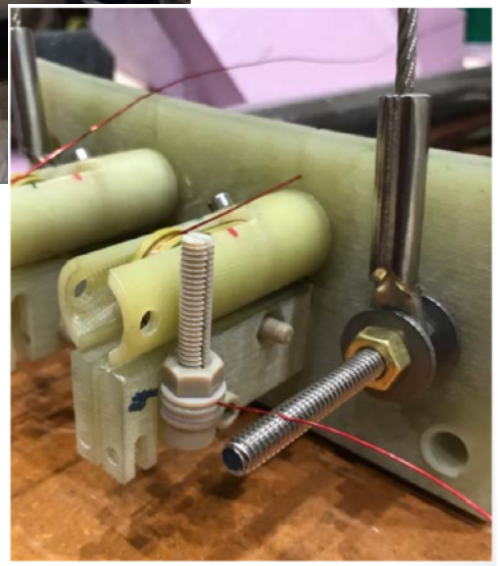
Component Status:

- R&D: two prototype testing successfully completed
- Assembly of the Internal Magnet Volume is in progress
- Vacuum jacket of magnet assembly has been delivered in Oct 2020
- coil support frame fabrication and end caps is completed
- cryogenic refrigerator has been delivered, cooling lines assembled and first cooldown is in progress
-

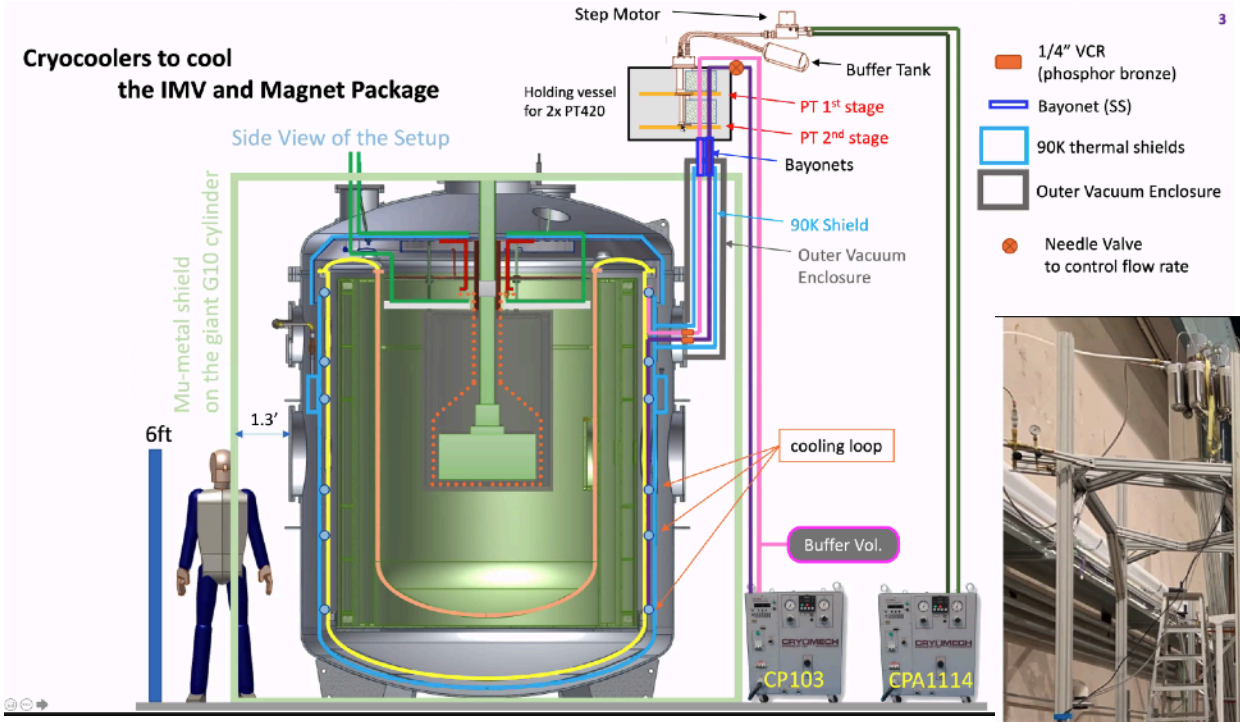


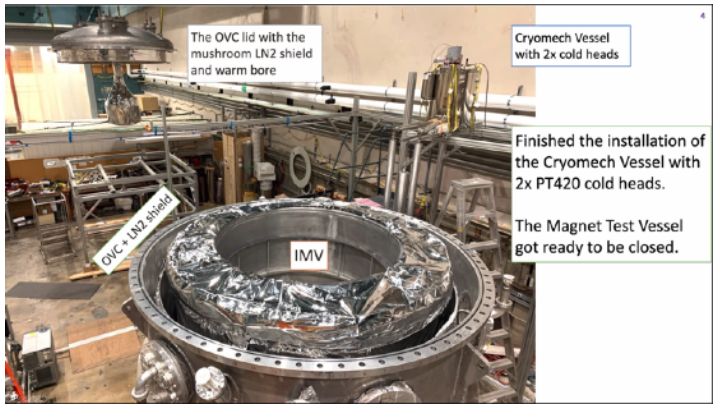
CRYOGENIC MAGNET SYSTEM



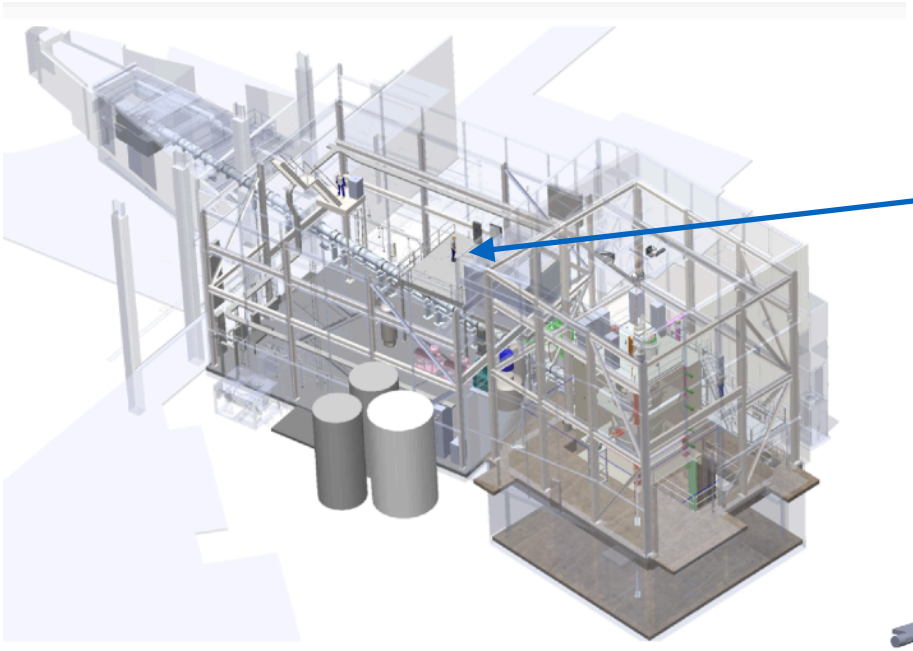


CRYOGENIC MAGNET SYSTEM

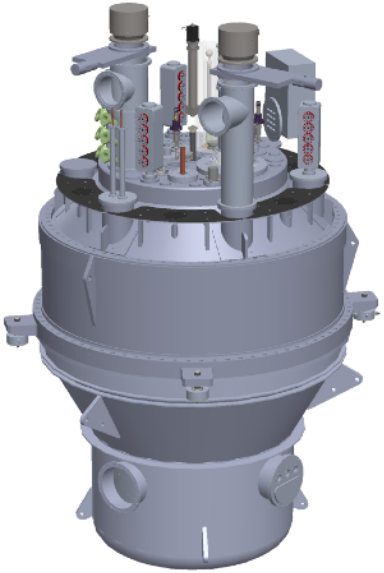


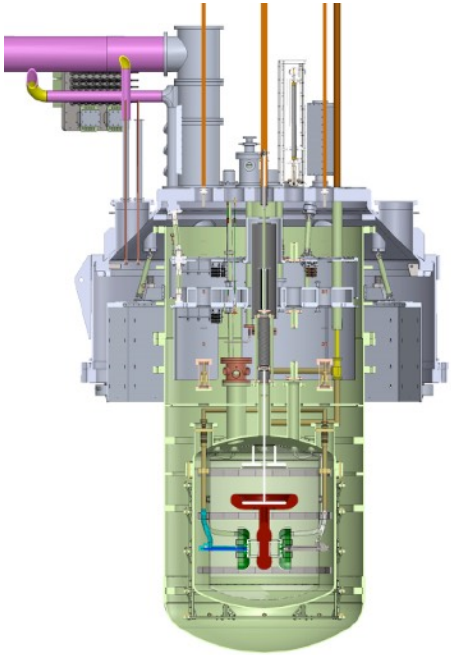


NEDM@SNS EXPERIMENT IN 2021



New mezzanine

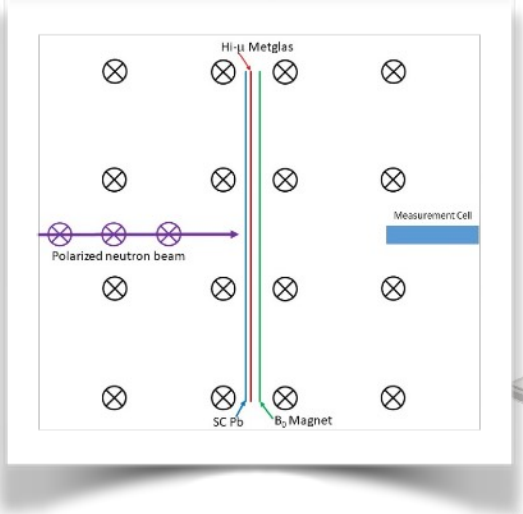




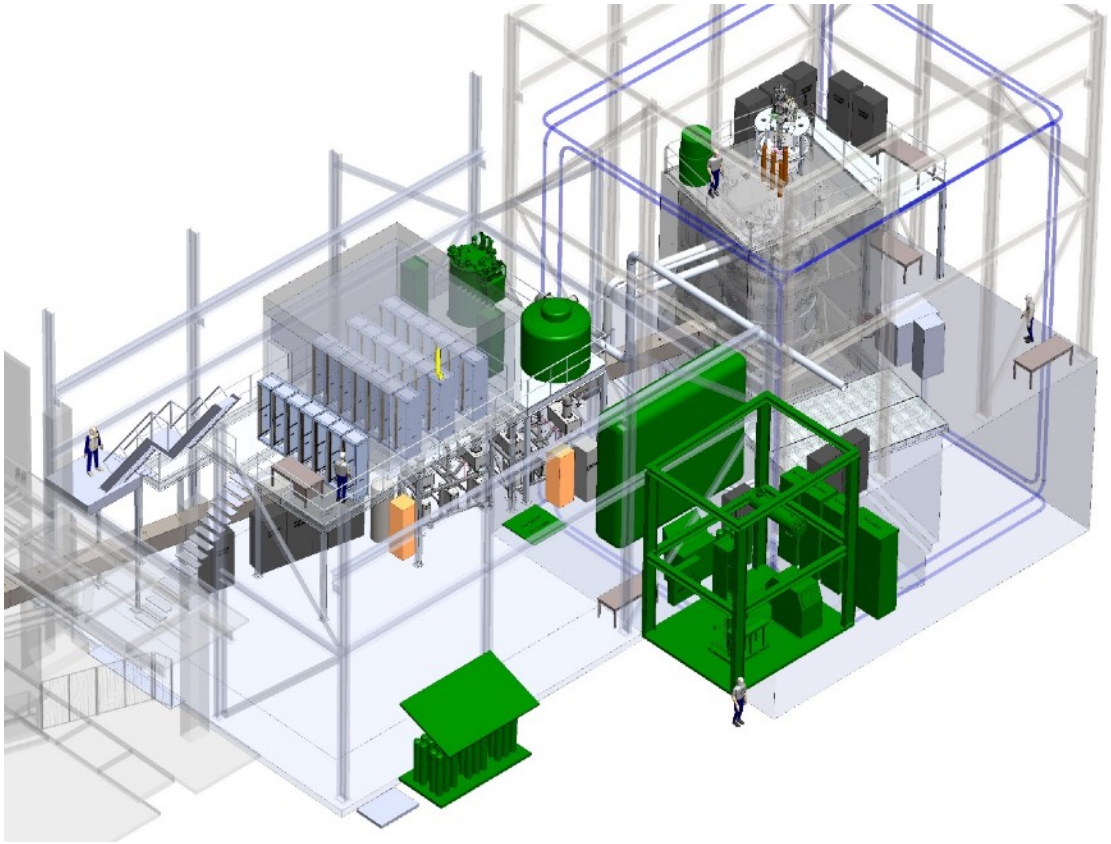
FIRST COMMISSIONING (STARTING IN 2021)

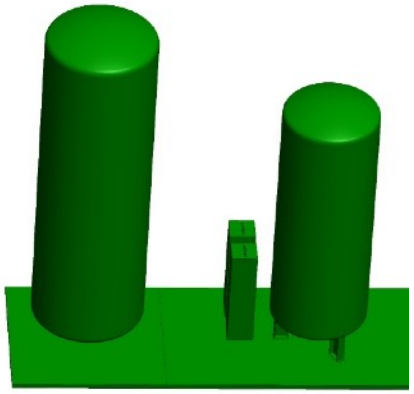
Polarization/Transmission Test

- Uses existing External Building 1 (EB1) & 9Å monochromator on beamline 13A



CRYOGENIC PLANT





SYSTEMATIC AND OPERATIONAL STUDY (S.O.S.) APPARATUS

SOS @ PULSTAR Reactor (NCSU)

- Polarized UCN & Polarized ^{3}He in a single cell (no HV)
- Allows testing of full size measurement cells
- Allows development of “Critical Spin Dressing” technique for ultimate sensitivity

Components status:

- 3He polarization and injection: assembly in progress
- Cryogenic system fully operational
- 4He circulation system and 3He removal system - first cool down in progress
- NMR spin manipulation electronic - components on hands and have been integrated together with software
- SQUID testing and integration with NMR : in progress
- Magnetic internal shields/coils - design near completion
- measurement cell interface: design and manufacturing drawings completed
- Earth field compensation coils - all control components assembled, waiting end of cool down to install the frame and coils

SUMMARY

- nEDM@SNS experiment is designed to use a new never realized (He-3+UCN) in LHe-4 technique:
  - have enough statistic means to push the upper limit of d_n down to lower 10^{-28} e-cm range.
  - Is not limited by geo-phase systematic.
  - has an upgrade mode (spin dressing) with increased statistic and independent set of systematic

- HV R&D still needs to be completed
- Technical development and fabrication of all subsystems is in progress
- First commissioning (measurement of neutron depolarization) is scheduled in Fall 2021

"A New Cryogenic Apparatus to Search for the Neutron Electric Dipole Moment" was published in the Journal of Instrumentation, Vol. 14, P11017, 2019.
It can be found here: https://iopscience.iop.org/article/10.1088/1748-0221/14/11/P11017

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