nEDM@SNS
Engineering Introduction

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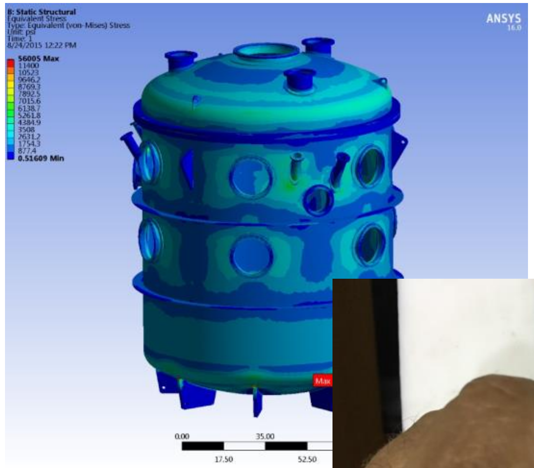
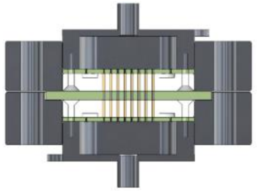
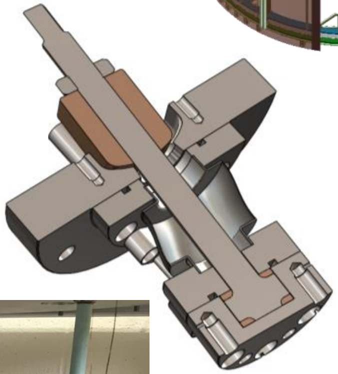
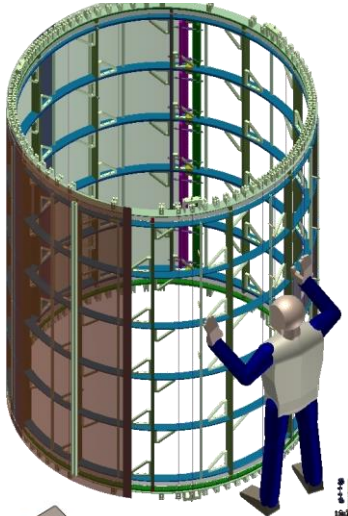
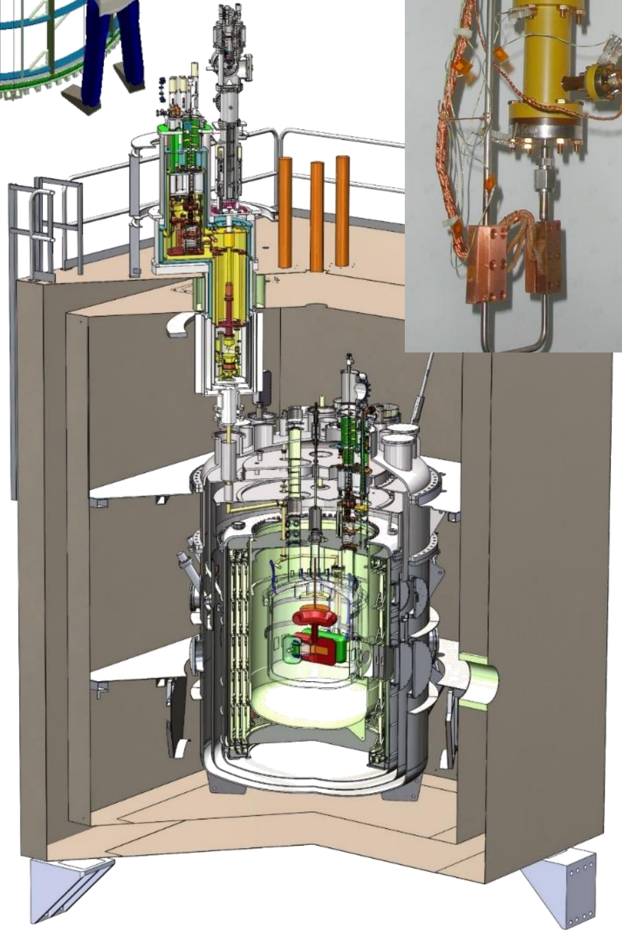










Outline

- Introduction to the Neutron Electric Dipole Experiment at SNS (nEDM@SNS)
- System overview and subsystem modules
- Engineering challenges specific to each subsystem
- Conclusions

Introduction to nEDM@SNS

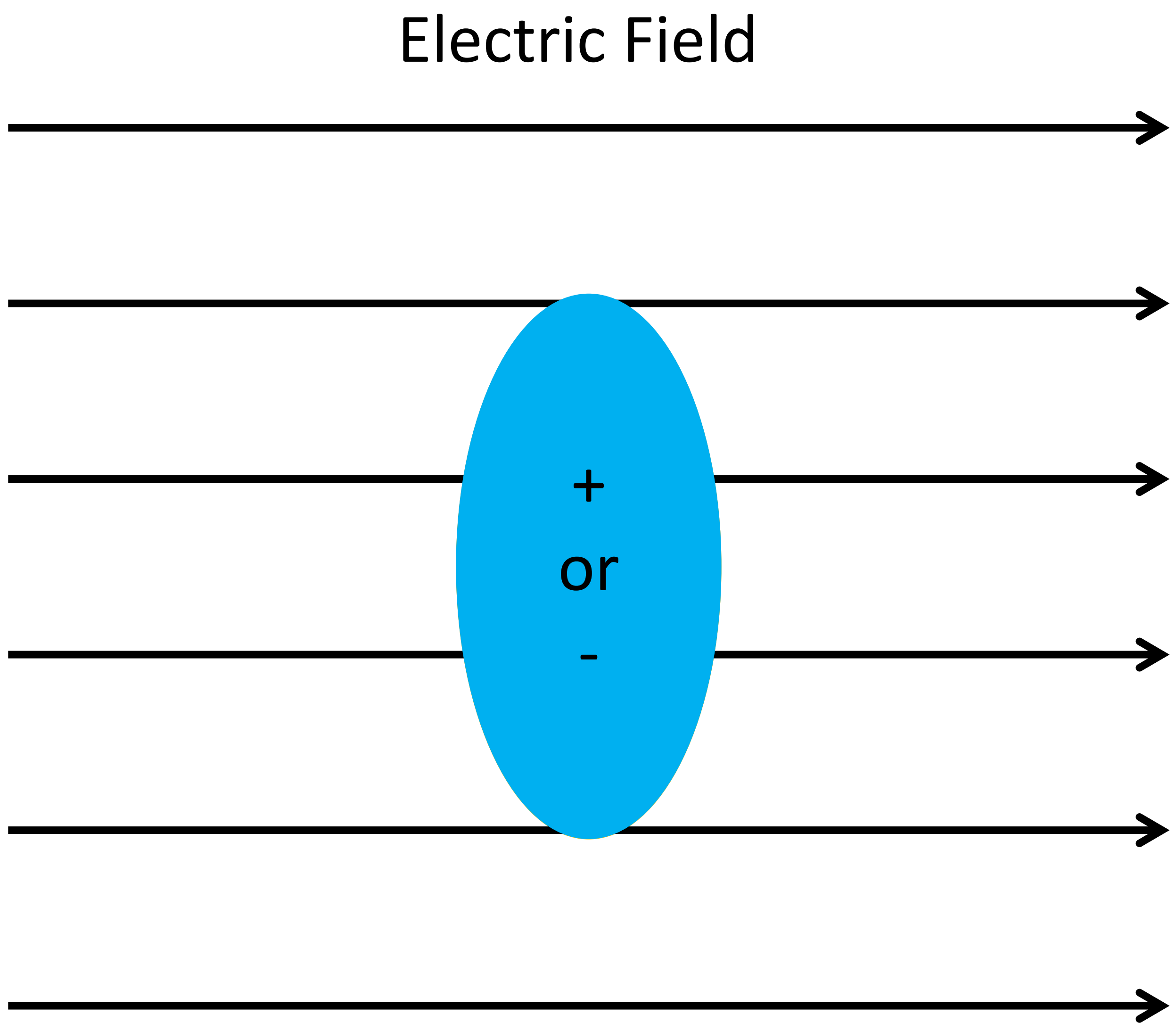
- Matter and antimatter created in equal amounts at the Big Bang
  - Should have resulted in complete annihilation :-o
  - **Why didn't it?**
- An electric dipole moment (EDM) is a measure of the separation of positive and negative charges (roundness) within a system
- A non-zero neutron EDM would mean that the neutron is not round
- This "out-of-roundness" would be an example of Charge-Parity(CP) violation, which is a possible explanation for matter/antimatter asymmetry

Introduction - continued

- nEDM@SNS will utilize a technique proposed by Golub and Lamoreaux* :
  - Polarized neutrons and polarized ^3He atoms are trapped in a bath of superfluid ^4He at a temperature of ~500 mK
  - When a magnetic field is applied, both the neutron and ^3He magnetic dipoles precess in the plane perpendicular to that field
  - The nEDM signal is the change in the neutron precession frequency when changing the electric and magnetic fields from parallel to anti-parallel and vice versa, assuming no change in the ^3He precession frequency

USING THIS METHOD, WE EXPECT TO IMPROVE UPON THE CURRENT WORLD CLASS MEASUREMENT BY ~2 ORDERS OF MAGNITUDE

REFERENCE: R. Golub and Steve K. Lamoreaux, “Neutron Electric-Dipole Moment, Ultracold Neutrons and Polarized ^3He”, Physics Reports 237, No. 1 (1994) 1-62 North-Holland.



Animation courtesy of Vince Cianciolo, ORNL

Introduction - continued

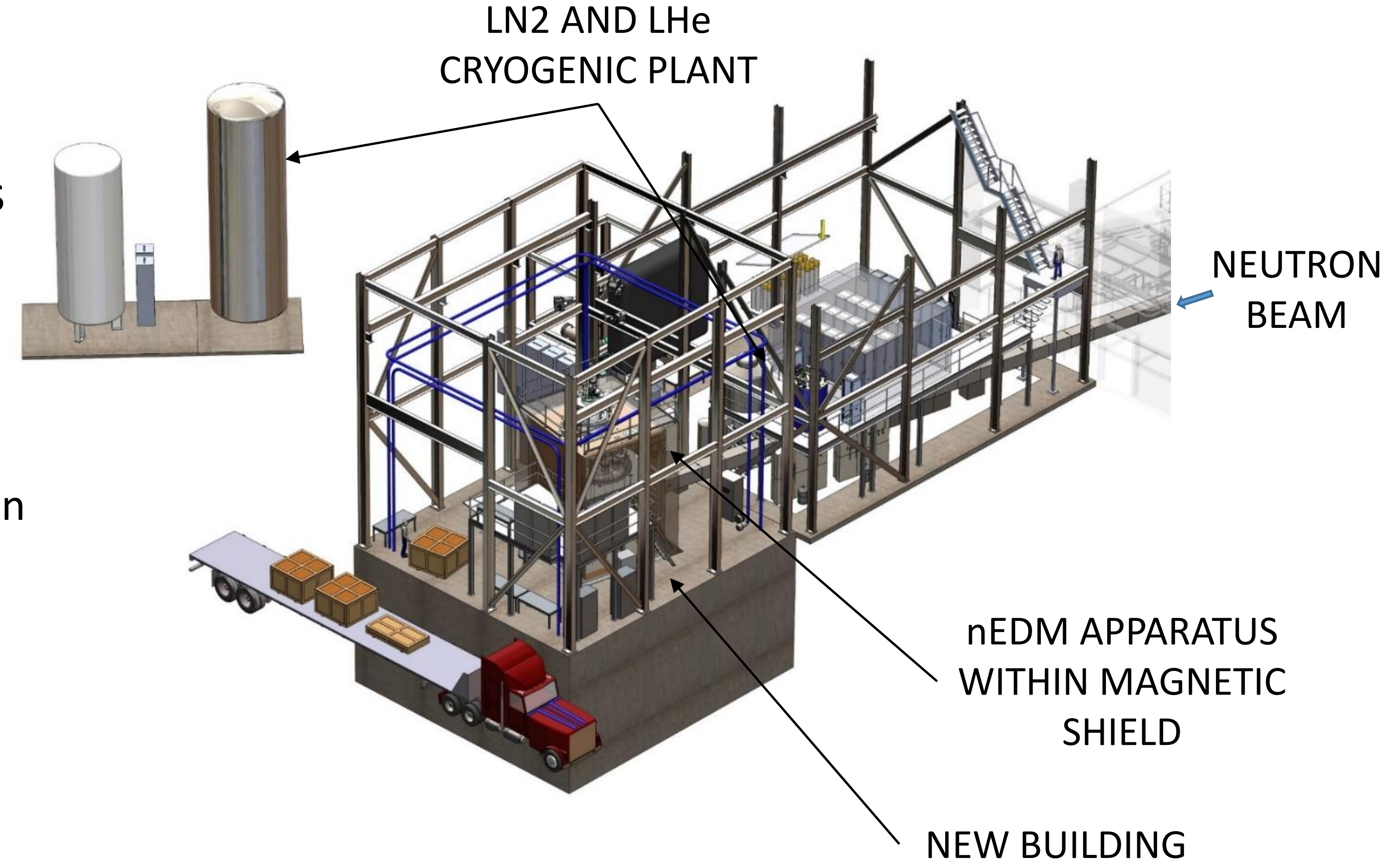
- Today we will focus on the engineering aspects of nEDM@SNS
- This talk describes the present snapshot of work in progress with contributions by many

Introduction - continued

- We have a technique and a strong team of physicists
- And a lot of work to figure out how to do it…
- They like to joke that the rest is “just engineering” ;-)
- But… more often than not, if there is a convenient existing engineering solution for some aspect of the experiment, we can’t use it!
  - Why? The requirements (magnetism, thermal and electrical conductivity, superconductivity, etc.) for actualizing this technique are very unique and preclude many standard practices

Overall nEDM@SNS system

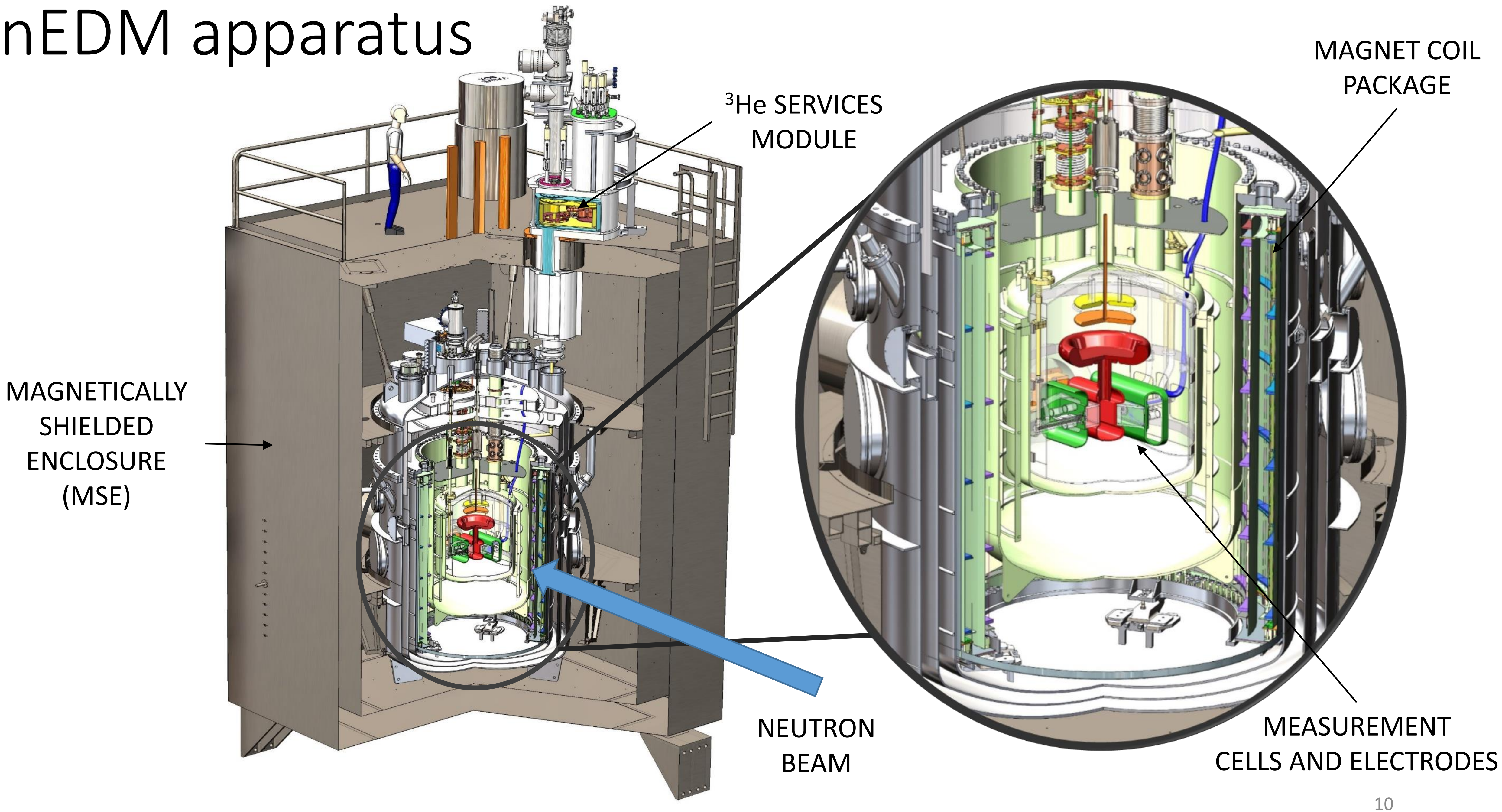
- The facility comprises:
  - nEDM apparatus – focus of this talk
  - New building
    - External magnetic field compensation
    - Non-magnetic foundation
  - Support services
    - Liquid helium plant
    - Liquid nitrogen
    - Magnetic shielding
    - Neutron guide



Subsystems in the nEDM design

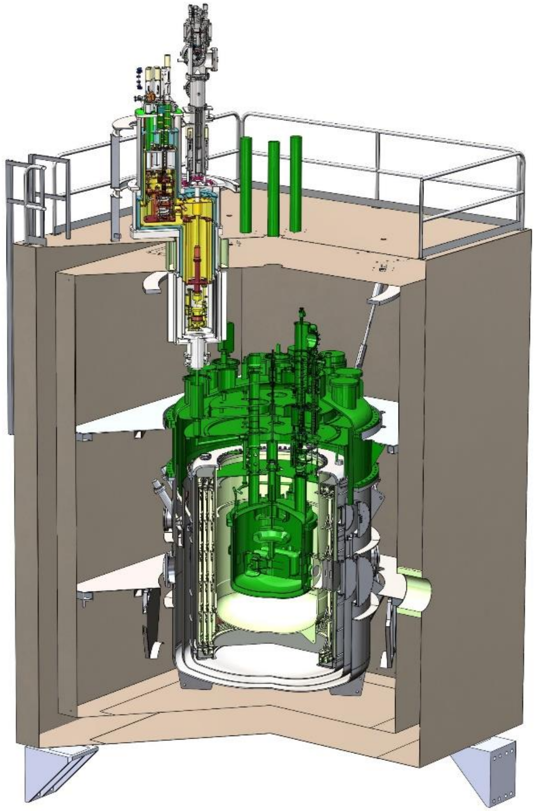
- The major internal subsystems were disentangled, minimizing and simplifying their interfaces
  - Central Detector Systems (CDS) module
  - Magnet module
  - ^{3}He Services module
- These modules may be assembled, tested, and debugged at their home institutions prior to final integration
- This independent testing will minimize the total number of full system cool-downs (and reduce frustration), shortening time to physics data

nEDM apparatus

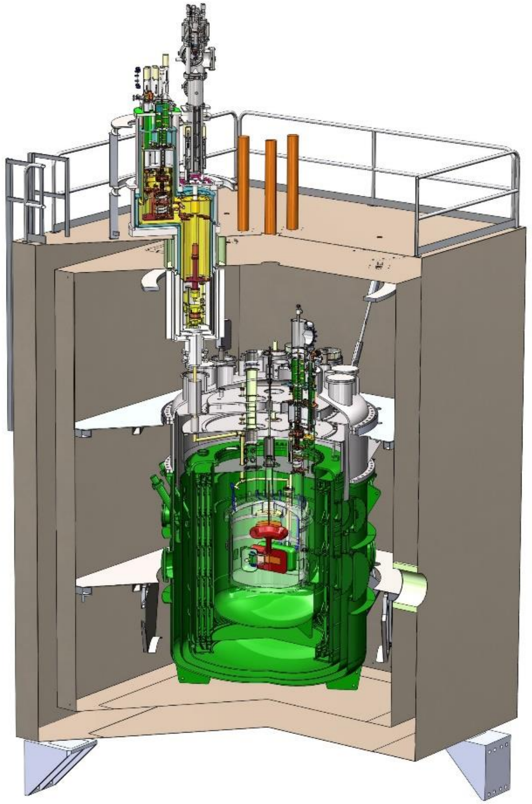


System modules

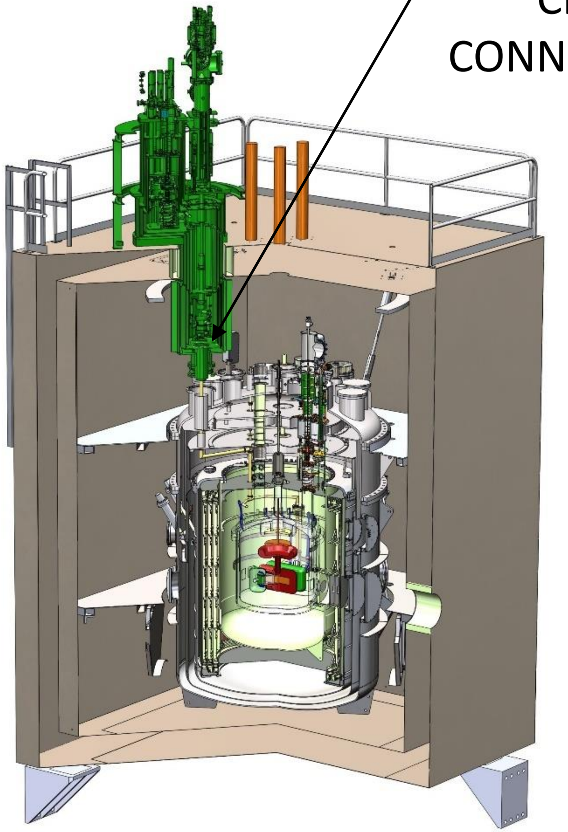
ONLY ONE INTERNAL CRYO CONNECTION!



CDS MODULE



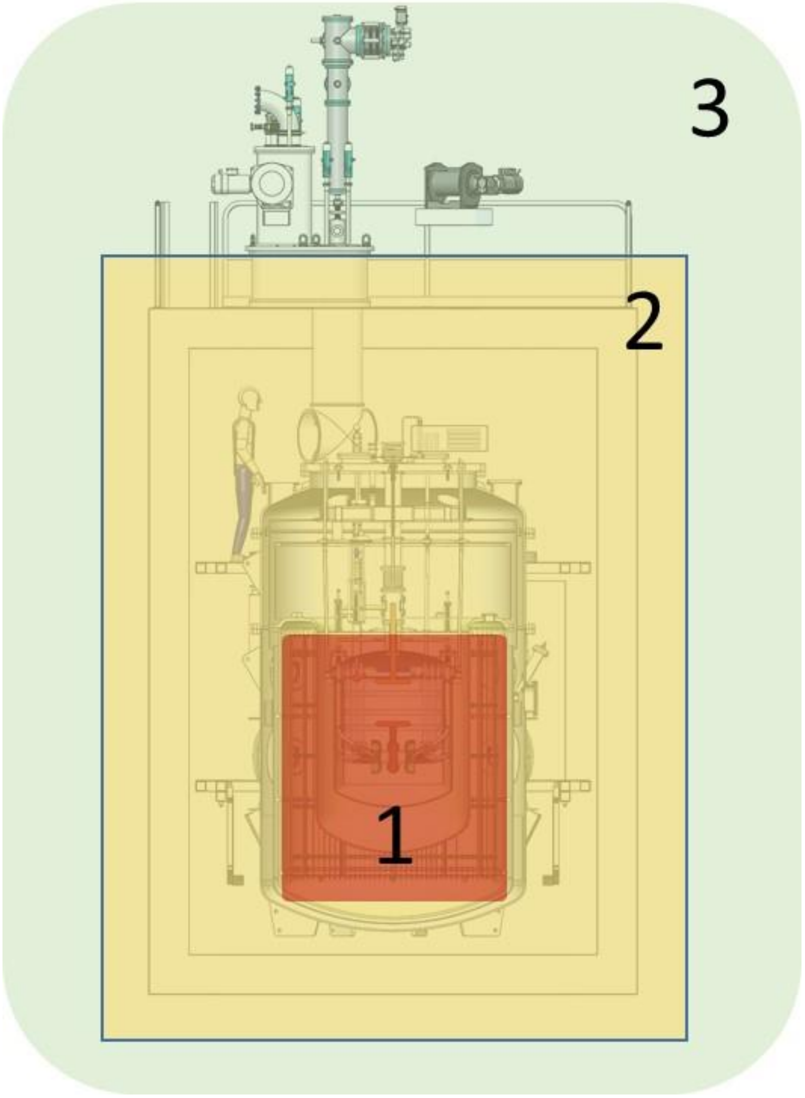
MAGNET MODULE



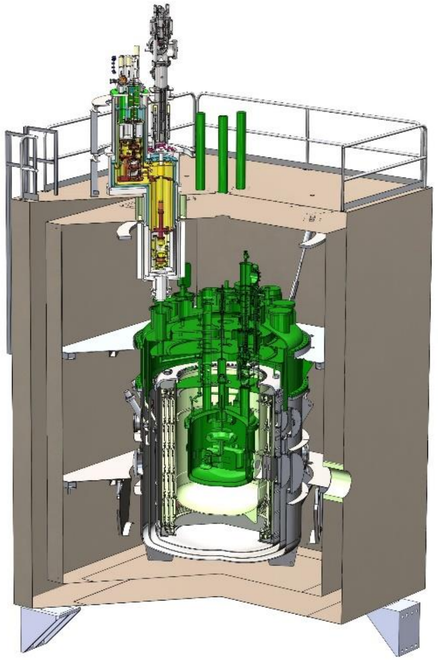
^{3}He SERVICES MODULE

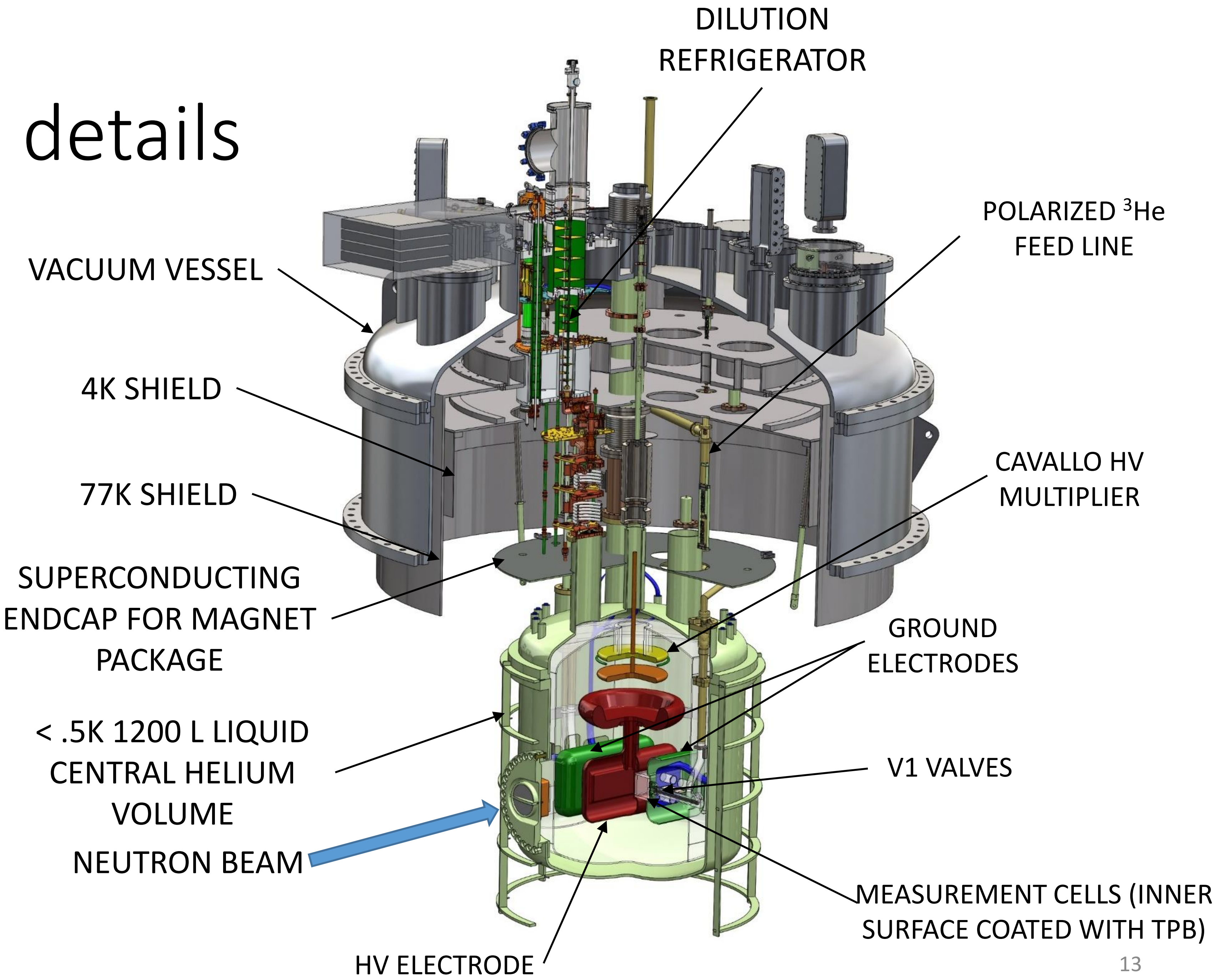
Sampling of requirements by location

- Region 1:
  - Non-magnetic
  - Non-metallic (wires and thin films acceptable with evaluation
  - Non-superconducting (specific material allowed with evaluation)
- Region 2:
  - Non-magnetic (stainless steel is generally too magnetic)
- Region 3:
  - Limited magnetism acceptable with evaluation



CDS module details



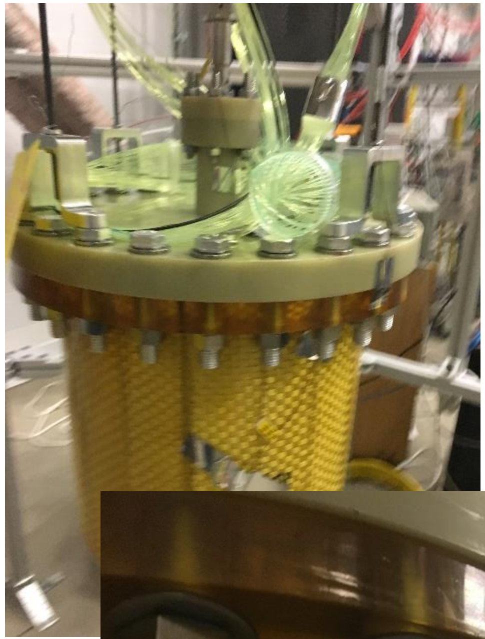


Key CDS engineering challenges
Regions 1 and 2

- Materials selection in Region 1
- V1 valve development
- HV delivery and multiplication
  - Previously planned a high voltage capacitor, but the scale to achieve the necessary gain became uncomfortably large
  - Currently studying voltage multiplication based on Cavallo’s multiplier, which delivers charge in multiple steps to the HV electrode

CDS materials selection
Regions 1 and 2

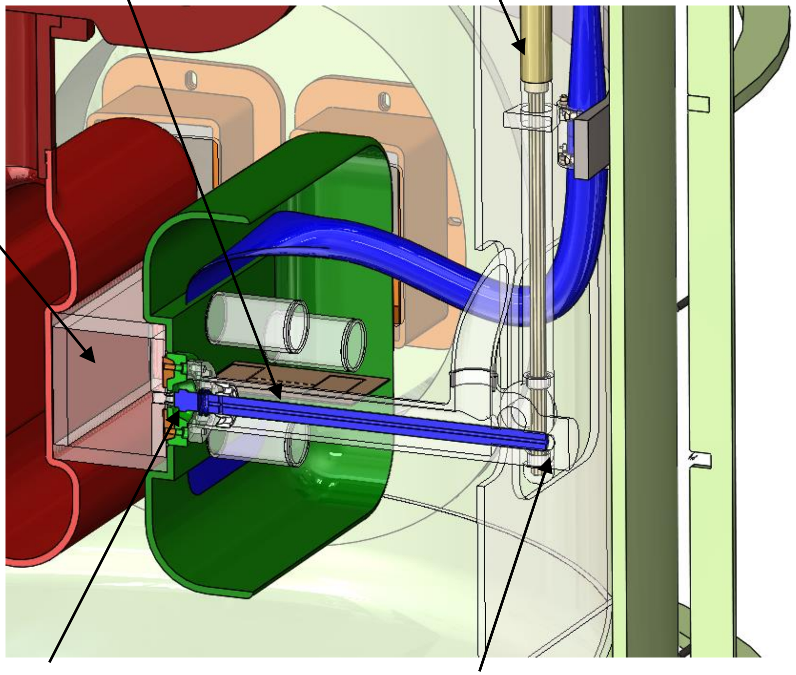
- Most materials in the central volume must be non-magnetic, non-metallic, non-superconducting, low activation, cryo-appropriate
- Metals are out for general construction
  - Vessel – glass fiber reinforced plastic
  - The measurement cells are acrylic for light transport purposes
  - We want thermal deformation to match wherever reasonable
    - Acrylic - copper implantation to make acrylic electrodes
    - PEEK (some PEEK contains impurities from production which activate badly!)
  - Other materials:
    - Torlon
    - Kapton
- Above the superconducting shield, non-magnetic, non-superconducting metals are allowed
  - Aluminum (depending on temperature)
  - Titanium (depending on temperature)
  - Copper and its alloys
  - $NiCoCr_x$

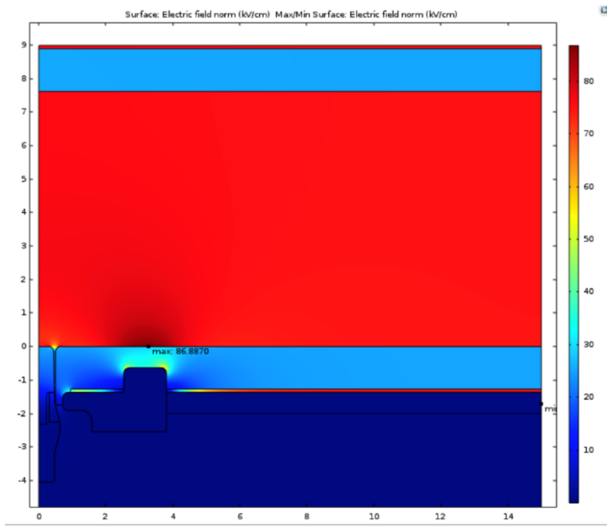


V1 valve development

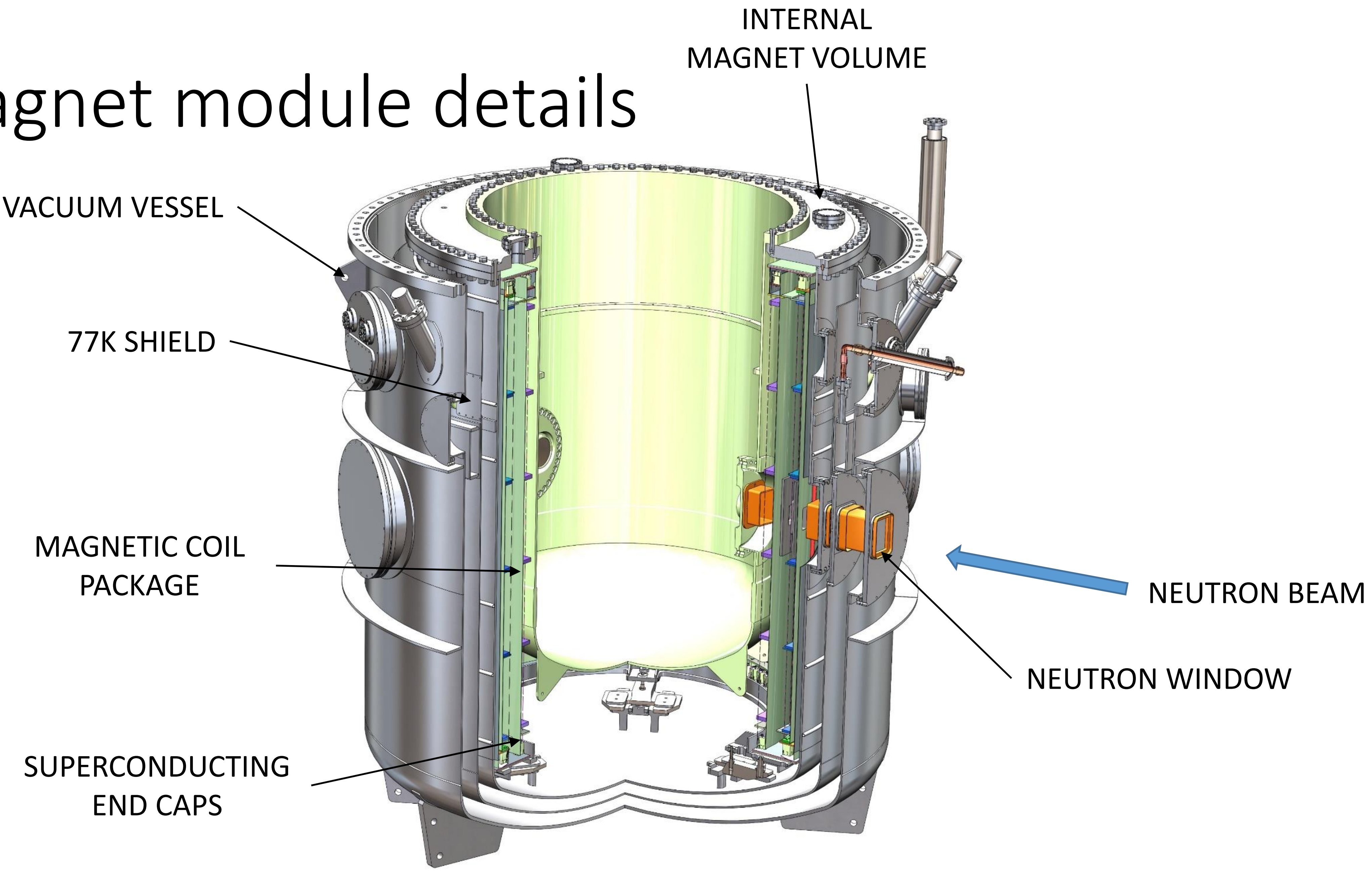
Region 1

- Geometry sufficient to transport ^{3}He
- ^{3}He depolarization time: τ_D > 20000s
  - PEEK, acrylic, and deuterated acrylic construction – Kapton coating possible if necessary
- Minimize valve impact on neutron storage
  - Most recent neutron storage time measurements at LANL have included realistic V1 geometry showing minimal valve impact
- Electrostatic
  - Maintain field consistent with the field uniformity spec when closed
  - No “hot spots” when open
  - Takeyasu Ito at Los Alamos National Laboratory is currently performing electrostatic modeling
- Minimize impact on light collection





Magnet module details



Key Magnet module engineering challenges

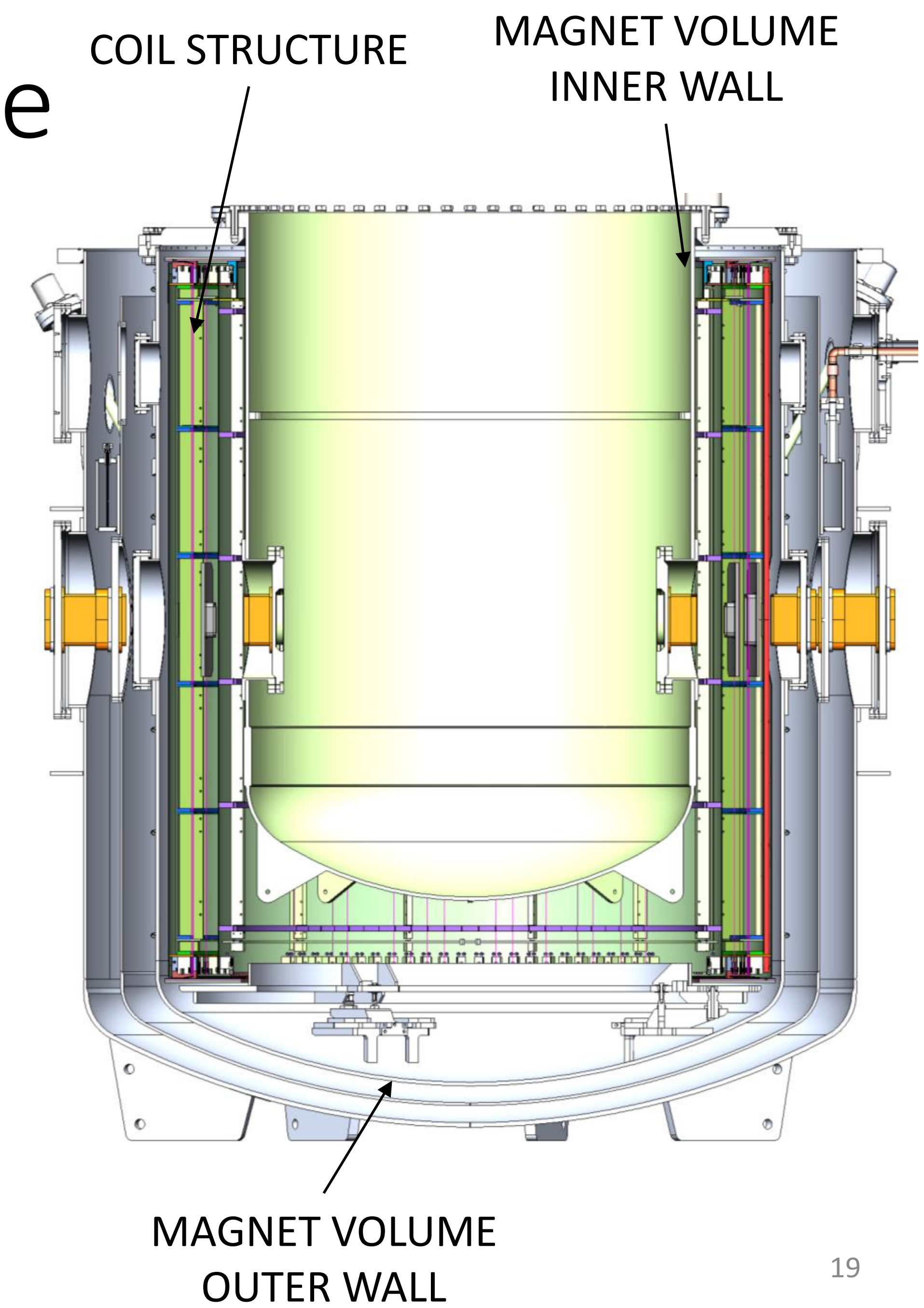
Regions 1 and 2

- <u>System cooling</u>
- Magnet volume design
- <u>Magnet coil package structure</u>
- Developing and maintaining necessary superconducting shield geometry

Cooling the magnet package

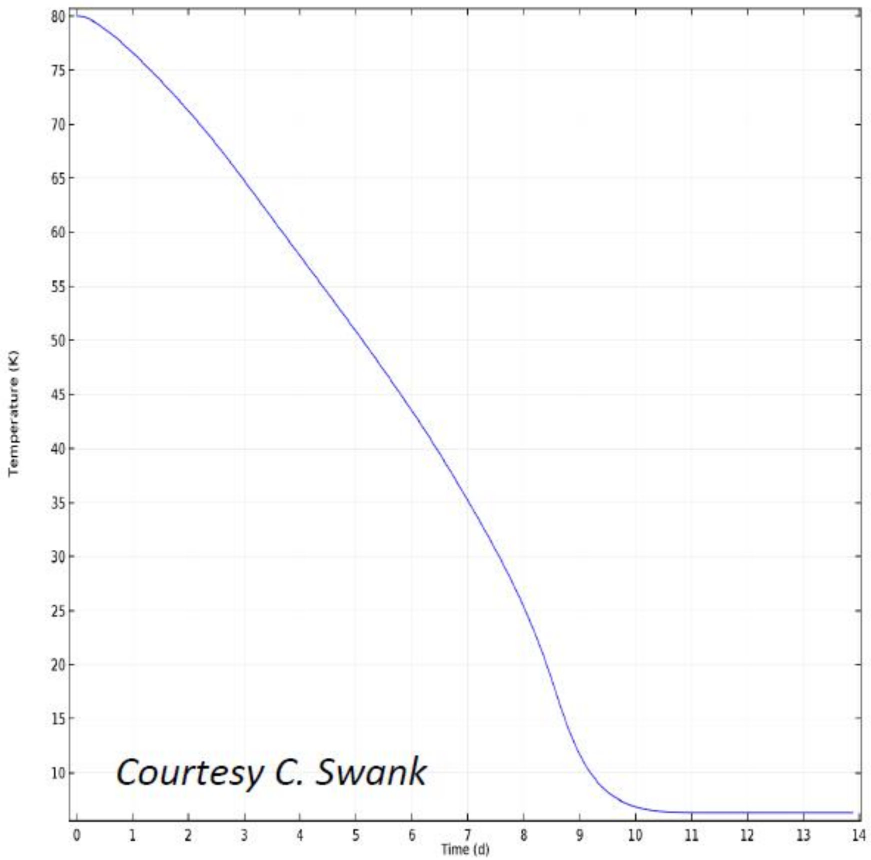
Regions 1 and 2

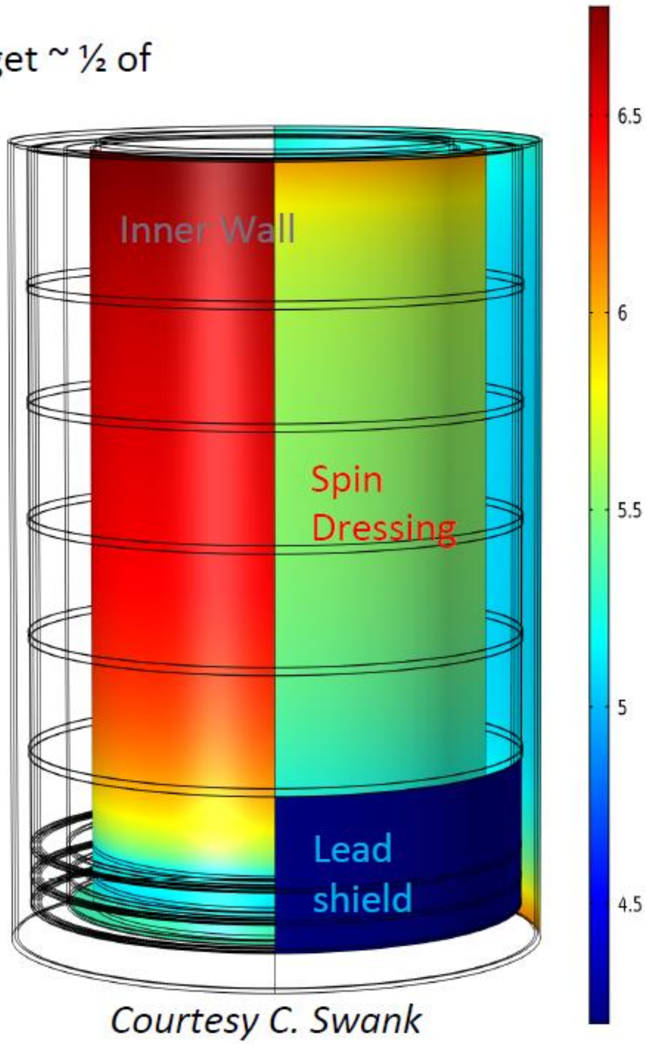
- The coil structures are largely glass-fiber reinforced plastic
- This material is a poor thermal conductor and maintains some specific heat even as the temperature drops
- Can be effectively cooled using exchange gas in the presence of cold surfaces



Cooling the magnet package - continued

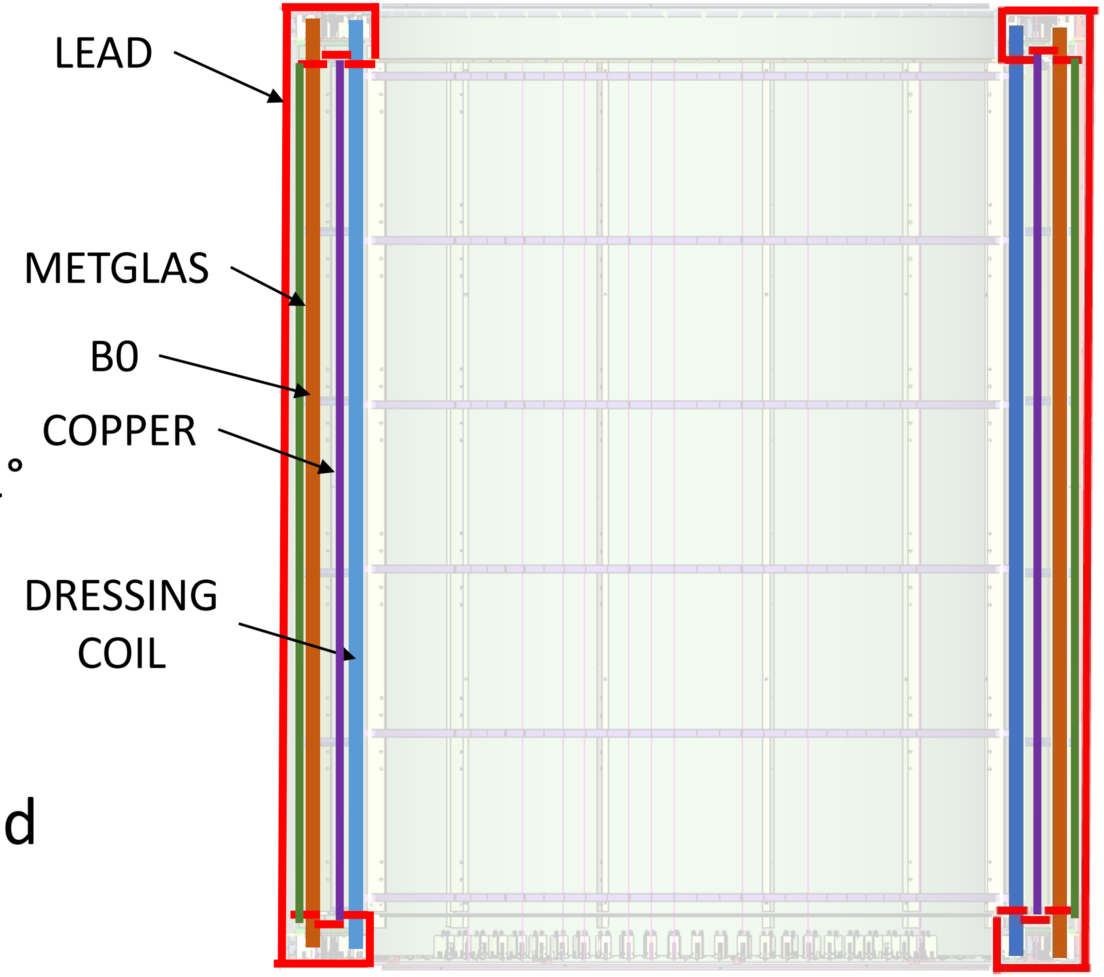
- Full Scale Cooling Model (COMSOL)
  - 9.5 days to cool at 6 l/h (assuming we get ~ ½ of enthalpy to 80K)
  - Everything is below 6.8 K





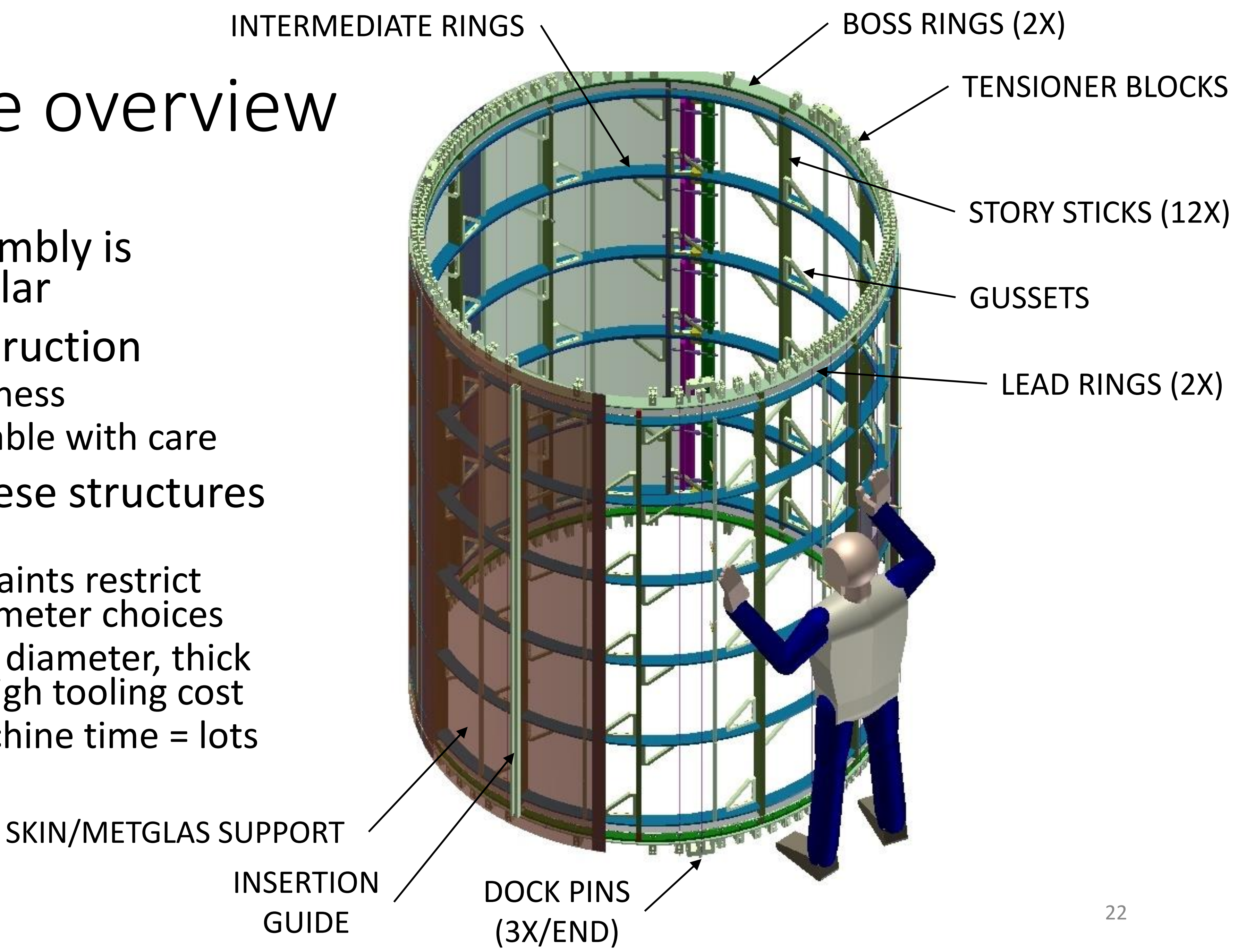
Magnet coil engineering

- Some assembly tolerance targets:
  - Wire positioning: +/- 1mm
  - Metglas radial placement: +/- 0.5 mm
  - Lead cylinder: +/- 10 mm
  - Lead endcap: +/- 3 mm
  - Copper placement: +/- 1mm
  - Clock position with respect to E-field: +/- 1°
  - Axial alignment with the cells: +/- 5 mm
- Shim coils will be employed to tweak the field as needed
- Structure should also provide features for assembly and some future undefined stuff



B0 structure overview

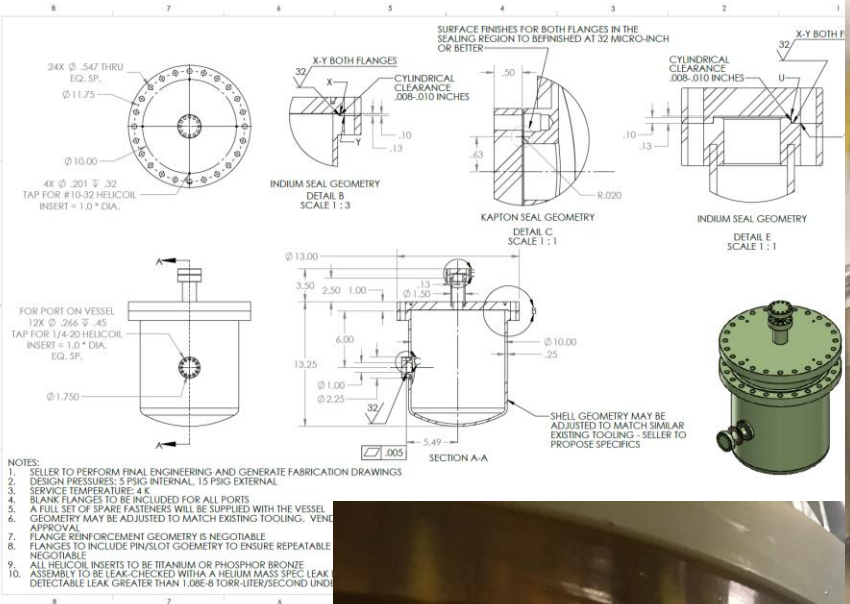
- Dressing coil assembly is mechanically similar
- Spaceframe construction
  - Appropriate stiffness
  - Precision achievable with care
- Why not make these structures from large tubes?
  - Packaging constraints restrict available coil diameter choices
  - Requires custom diameter, thick starting tube – high tooling cost
  - Lots of large machine time = lots of $$



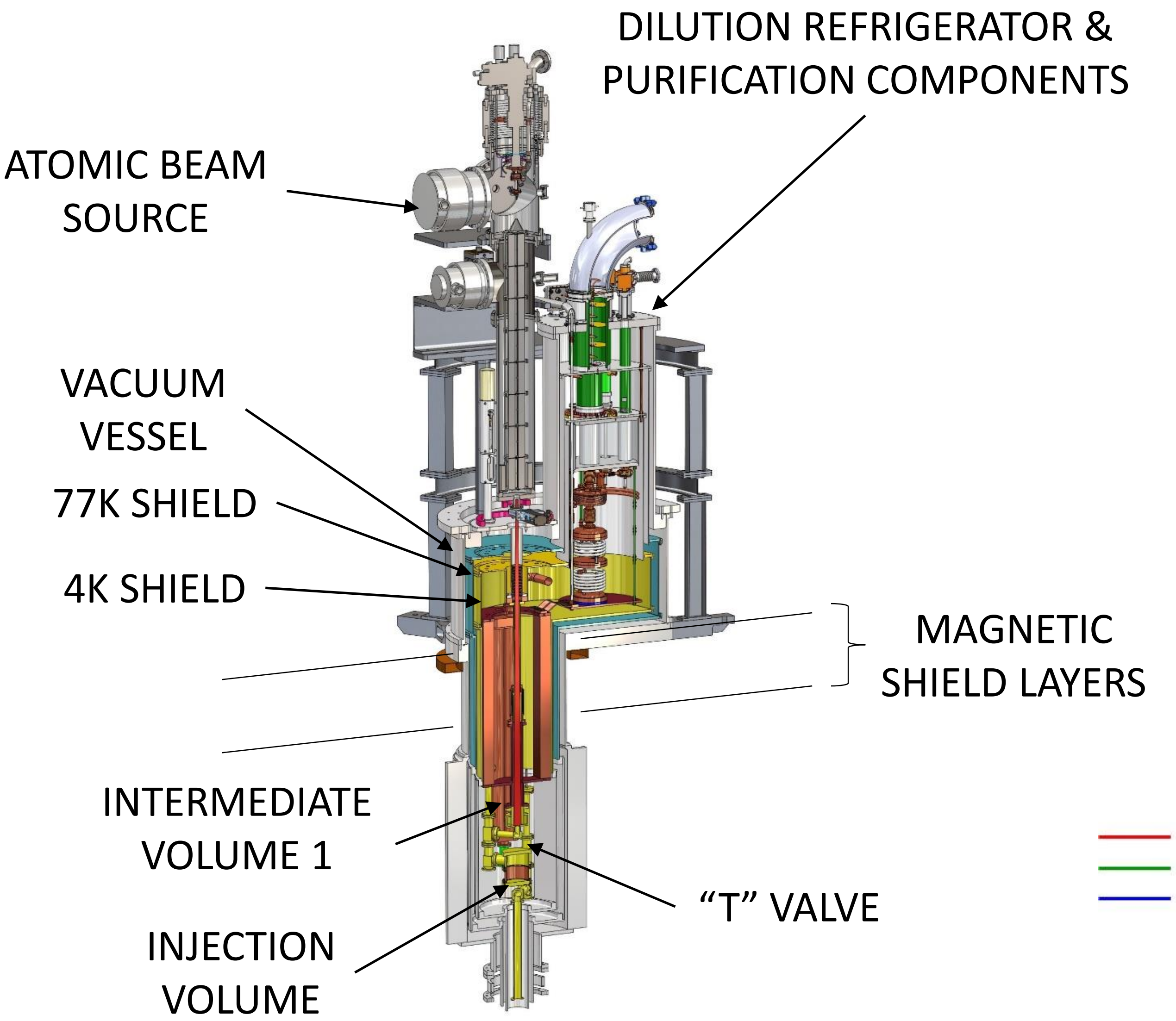
Non-magnetic, non-metallic vessels

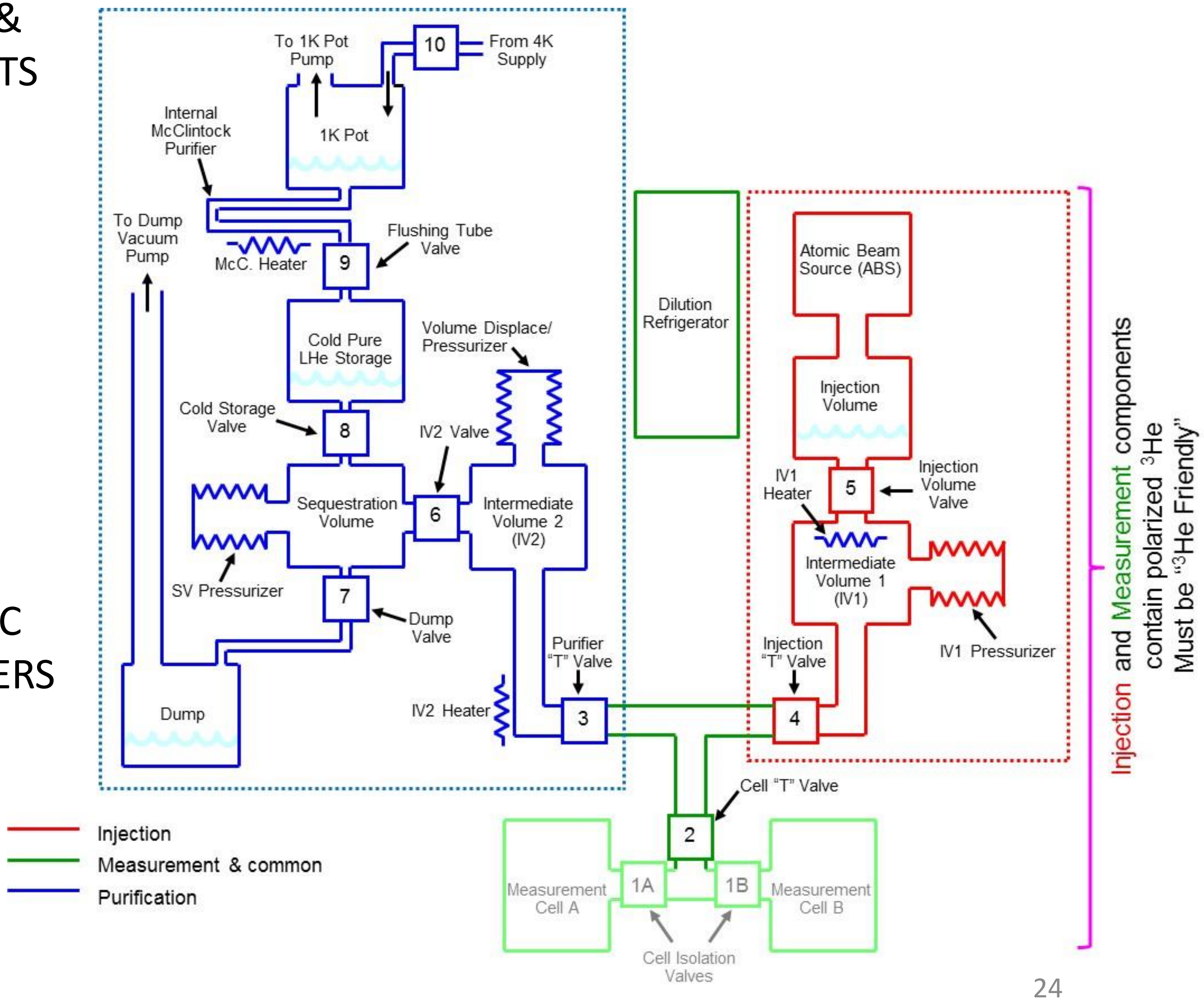
Region 1

- Inner wall of the Magnet Volume and the whole Central Volume must be non-conductive to avoid eddy-current heating
- The collaboration has prior experience with glass-fiber reinforced plastic (GFRP)
- Currently developing test vessels to test materials and geometries



^{3}He Services module details





Key ^{3}He Services engineering challenges

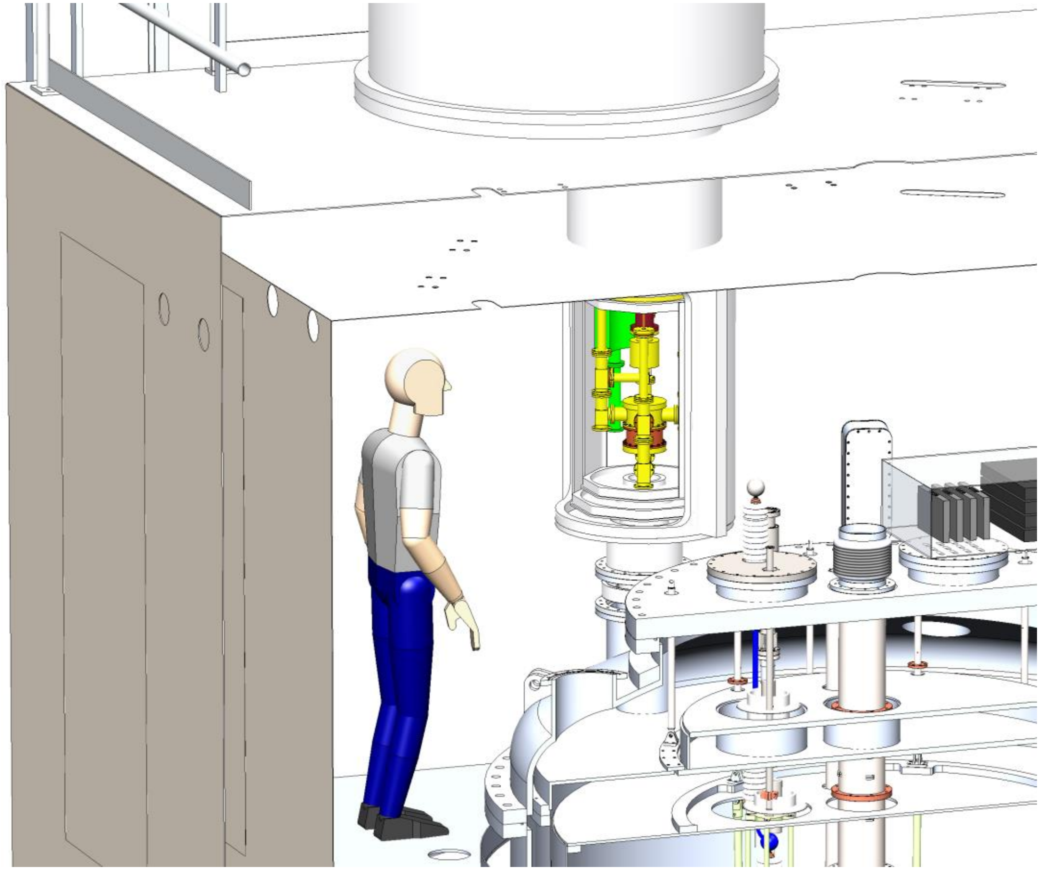
Regions 2 and 3

- Umbilical connection access
- Upper cryostat component access
- Tee valve development
- Thermal control
- Materials / fabrication
  - ^{3}He must be delivered to the measurement cells while maintaining polarization – Torlon piping

Accessing the ^{3}He Services umbilical connection

Region 2

- There is a single internal cryogenic connection between the ^{3}He Services module and the CDS, but it is complex
  - Torlon piping/flanges
  - Kapton gasket
  - Heat load control critical
- Some components of the ^{3}He Services system are within the shield house near the joint
- Evaluating paneled radiation shield concept and windowed vacuum jacket to maximize accessibility



Tee valve development

Regions 2 and 3

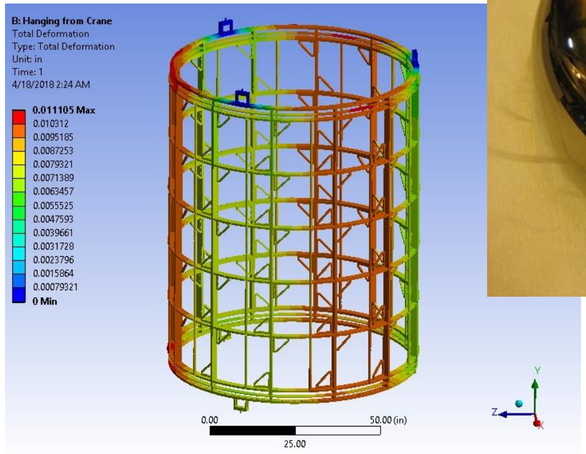
- Torlon Body
  - Machined cylinders
  - No mechanical problems (e.g. stress failures)
- Flange Seals
  - V-groove/Kapton gasket seals
  - Silicon-bronze bolts
  - No blind tapped holes
  - Different materials
    - Torlon-to-Torlon
    - Copper-to-Torlon
    - Stainless Steel-to-Torlon
  - **No leaks** into internal vacuum volume

Materials courtesy of Steve Williamson, UIUC

Conclusions

- The nEDM apparatus is a complex system intended to improve on the current world-class measurement of the neutron electric dipole moment by two orders of magnitude
- The project presents plenty of engineering challenges, but persistence, teamwork, and a dose of creativity can bring them to ground

Questions?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Total Deformation
Type: Total Deformation
Unit: in
Time: 1
4/18/2018 2:24 AM
0.011105 Max
0.010312
0.0095185
0.0087253
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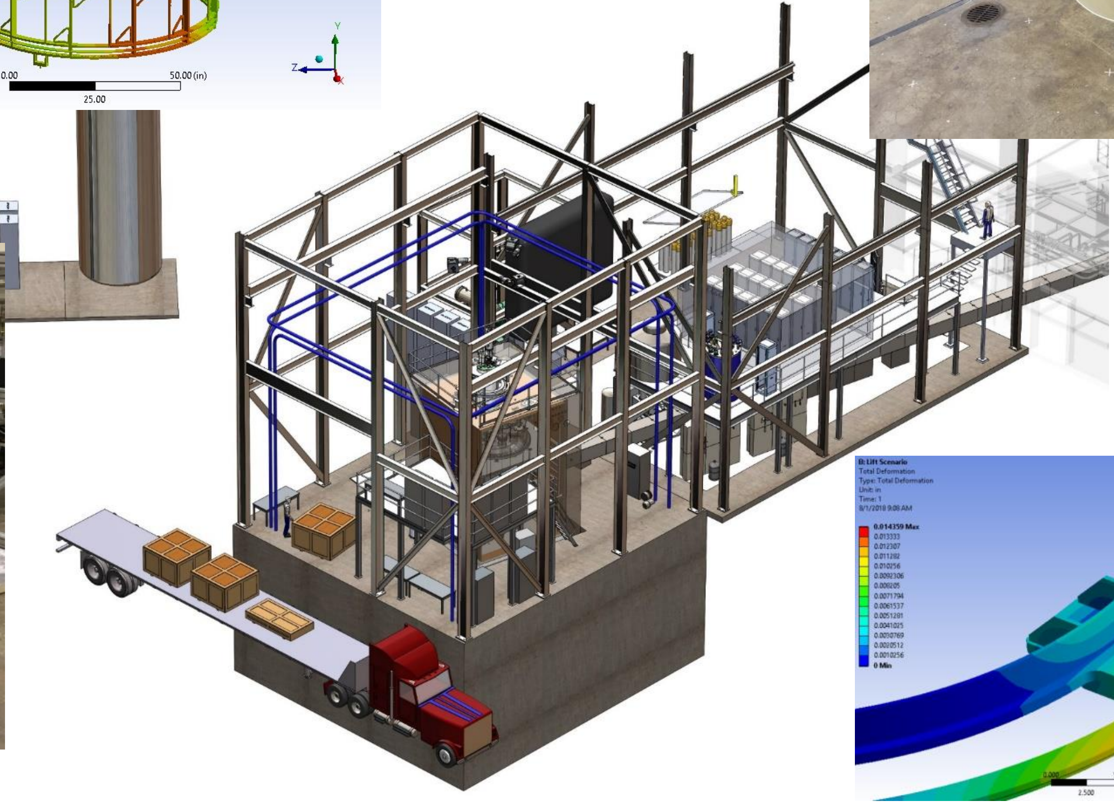
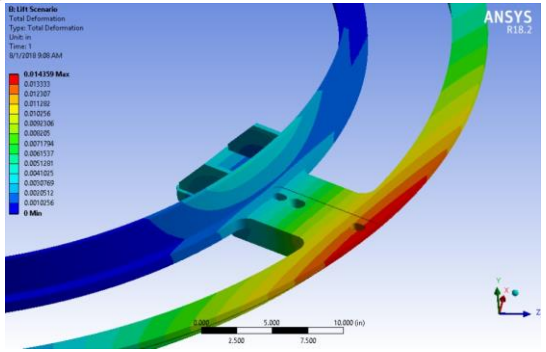
25.00


PMMA Copper
Feb. 2015
#1 (Top)




B: Lift Scenario
Total Deformation
Type: Total Deformation
Unit: in
Time: 1
0.014359 Max
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R18.2