NATIONAL HIGH MAGNETIC FIELD LABORATORY

# Magnets for Scattering & Axion Detection

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# Axion Basics

~95% of the universe is believed to consist of dark matter & energy.

Axions are one of several candidate particles that might constitute dark matter.

The Power of some axion detectors is given:

$$P = \kappa \mathcal{G} V \frac{Q}{m_a} \rho_a g_{a\gamma}^2 B_e^2,$$

Approximate as $B_0^2 V$: square of central field multiplied by volume of detector.

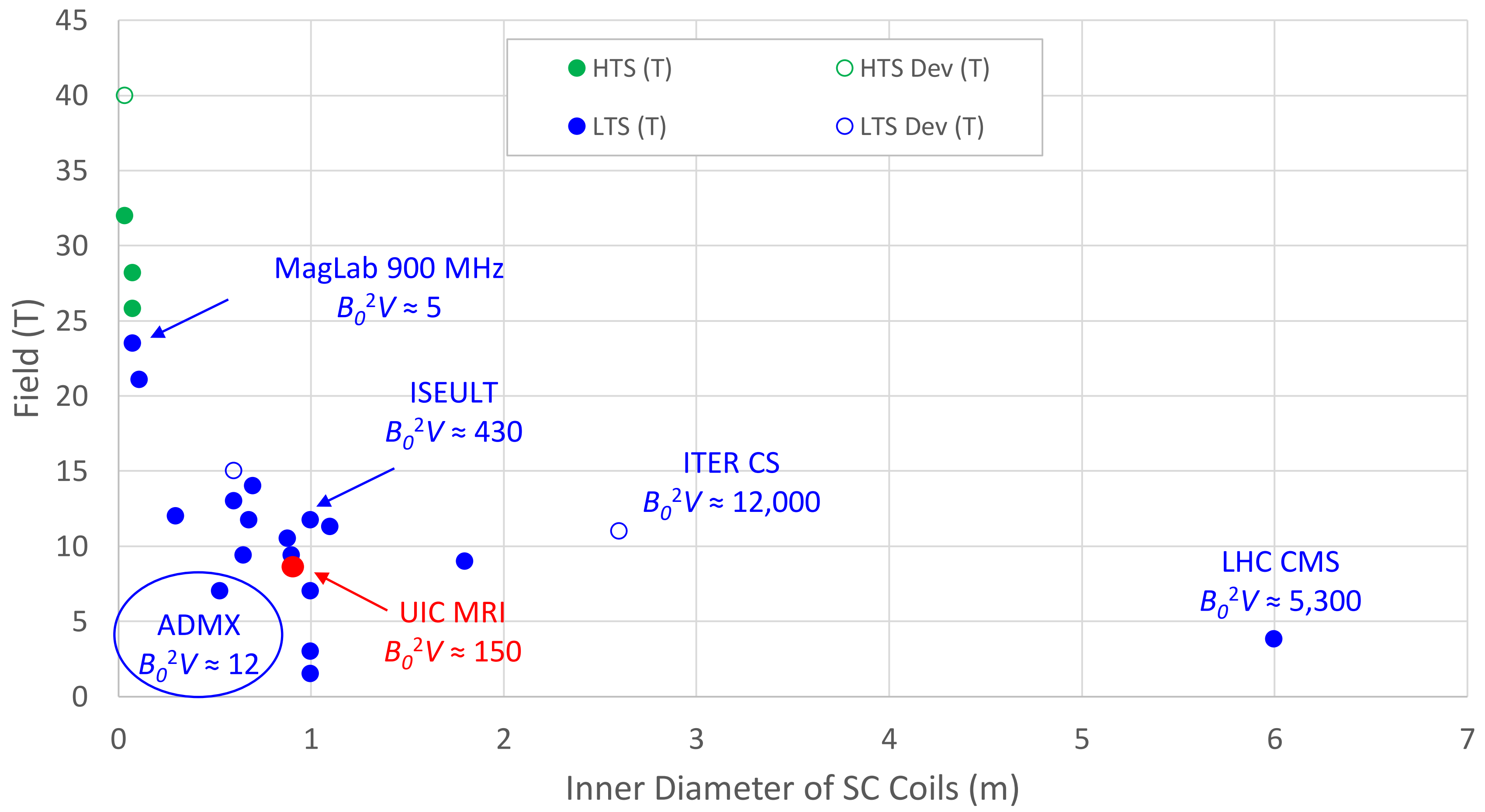
A resonator of some sort is installed in the magnet:

Sikivie haloscope (1983) = radio frequency (rf) cavity

(Axion Dark Matter eXperiment = ADMX)

Lawson, et al., *PRL*, **123**, 142802 (2019)

# Field vs Bore of some Superconducting Solenoids Worldwide



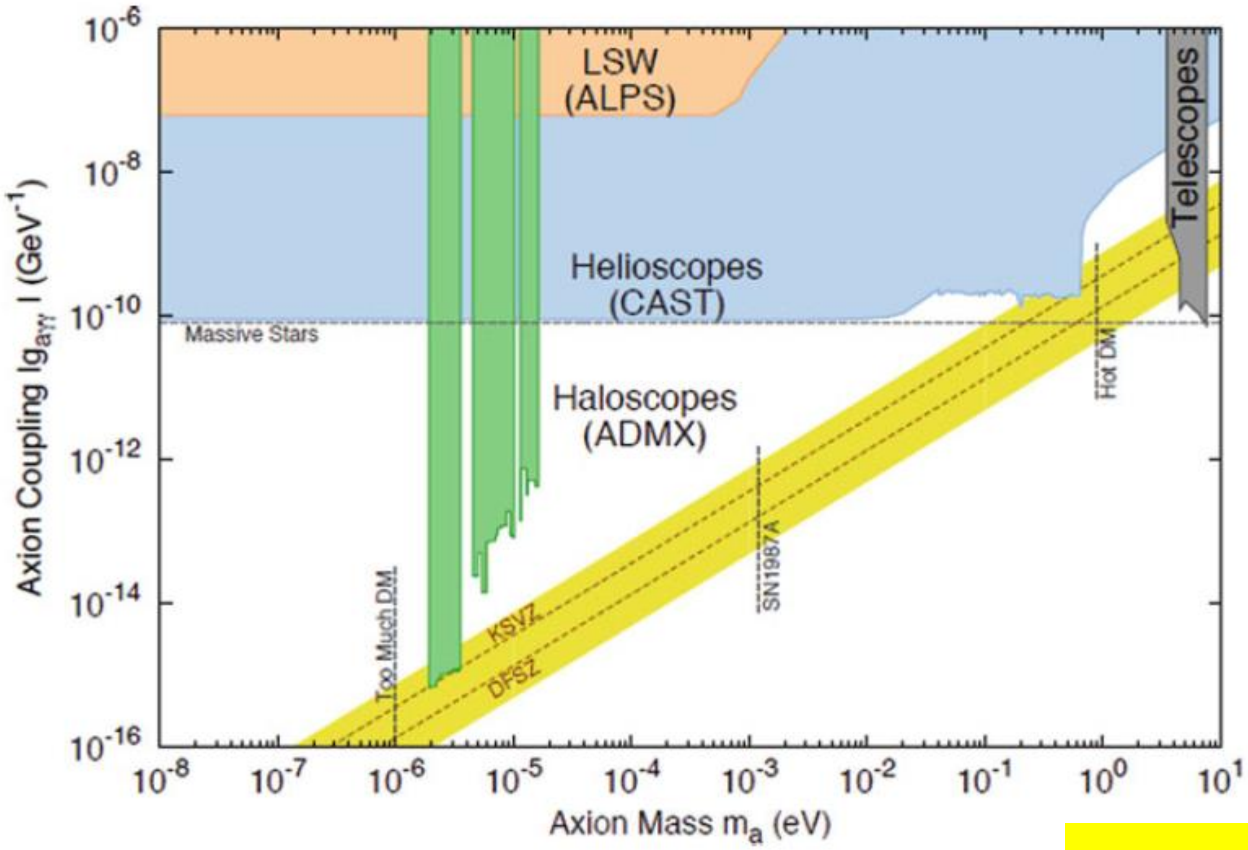

To maximize $B_0^2V$: ITER CS (11 T, 2.6 m, ~12,000 $T^2m^3$).

To get higher $B_0^2V$ than the existing ADMX: UHF MRI magnet.

ADMX recently acquired a 9.4T MRI magnet built by Magnex/GE and owned by the University of Illinois at Chicago (UIC). (150 $T^2m^3$)

LTS = Low Temperature Superconductors (NbTi, $Nb_3Sn$)
HTS = High Temperature Superconductors (REBCO, Bi-2223, Bi-2212)

# Some Limitations in the Resonator Size for Sikivie Haloscope




The Axion is expected to have a mass between $10^{-6}$ and $10^{-3}$ eV.

## Diameters of ADMX rf cavities

| | |
|---|---|
| Existing cavity | 0.40 m |
| Cavity required for next octave | 0.07 m |

We can only slave a few cavities together.

Next generation magnet for ADMX should have a bore of ~0.15 m with as high a field as possible (~30 T?). Similar to 40 T project.

Carosi & Rybka, eds., *Microwave Cavities and detectors for Axion Detection*, (202)

# Plasmonic Haloscope

A resonator of some sort is installed in the magnet:

~~Sikivie haloscope (1983) = radio frequency (rf) cavity~~

~~(Axion Dark Matter eXperiment = ADMX)~~

Plasmonic haloscope (2019) = array of parallel metamaterials wires

(Axion Longitudinal Plasma Haloscope = ALPHA) (Frank Wilczek)

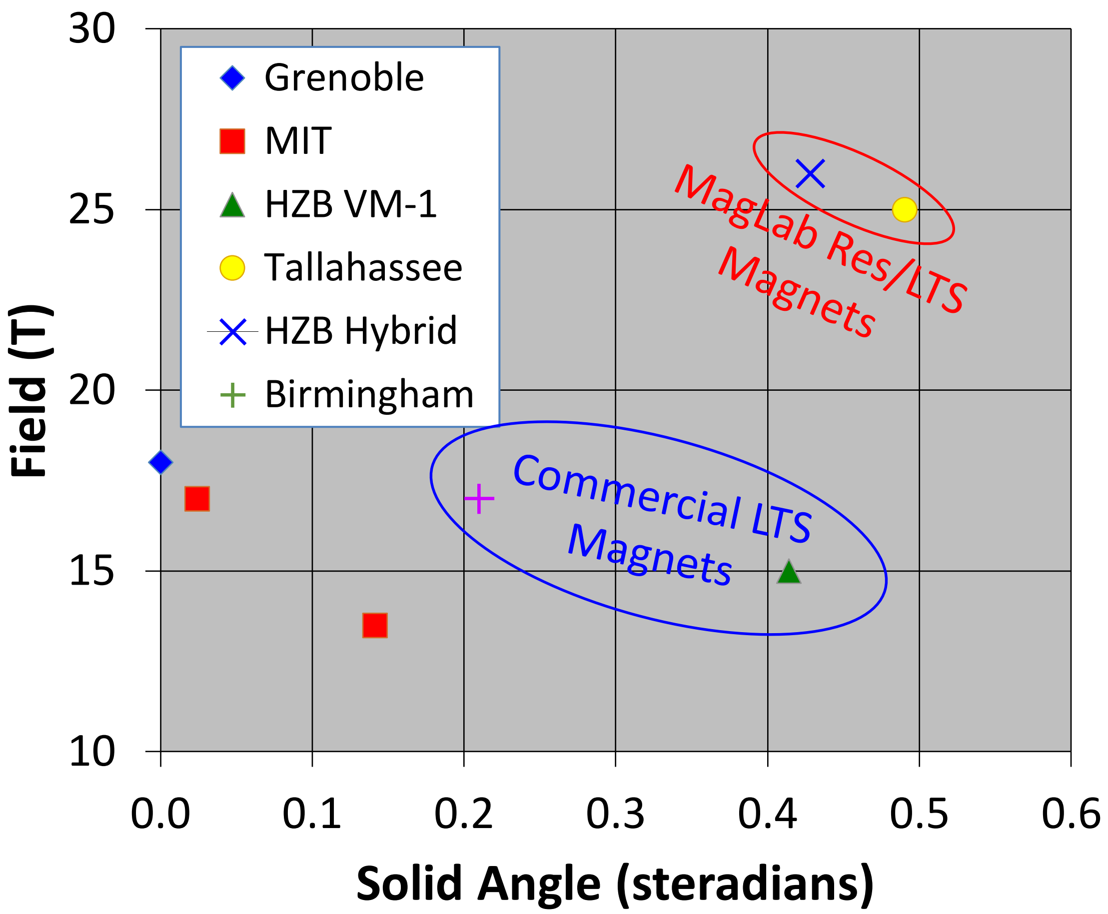
If the Plasmonic Haloscope works as intended, its resonator will not have the size limitation of the Sikivie Haloscope.

Next generation magnet for ALPHA should:

Maximize $B_0^2V$ subject to a cost constraint.

Similar to our hybrid outserts.

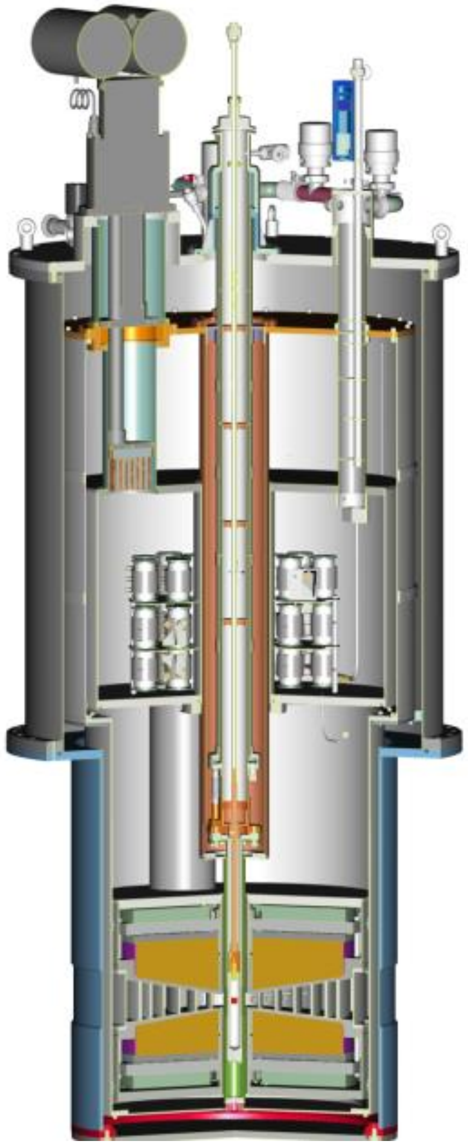
# State of The Art for Scattering Magnets

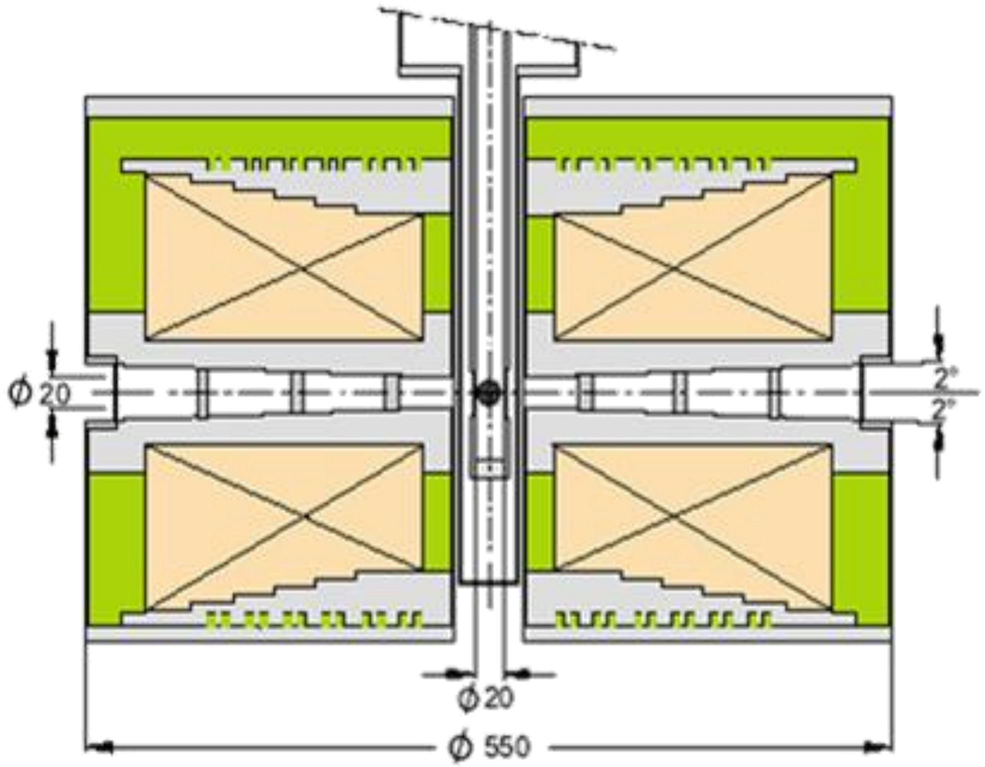


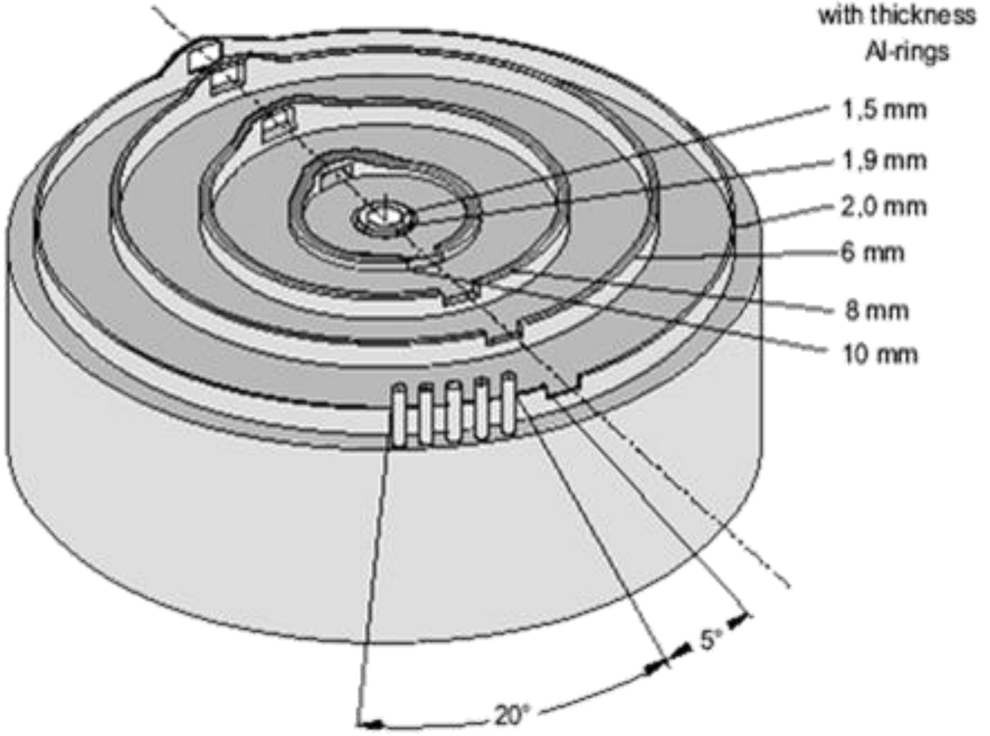
# Vertical Field Split Magnets

**15 T SC** Vertical Field Split-Pair for Neutron Scattering

Similar magnets for x-rays use “wedges” instead of “rings”.



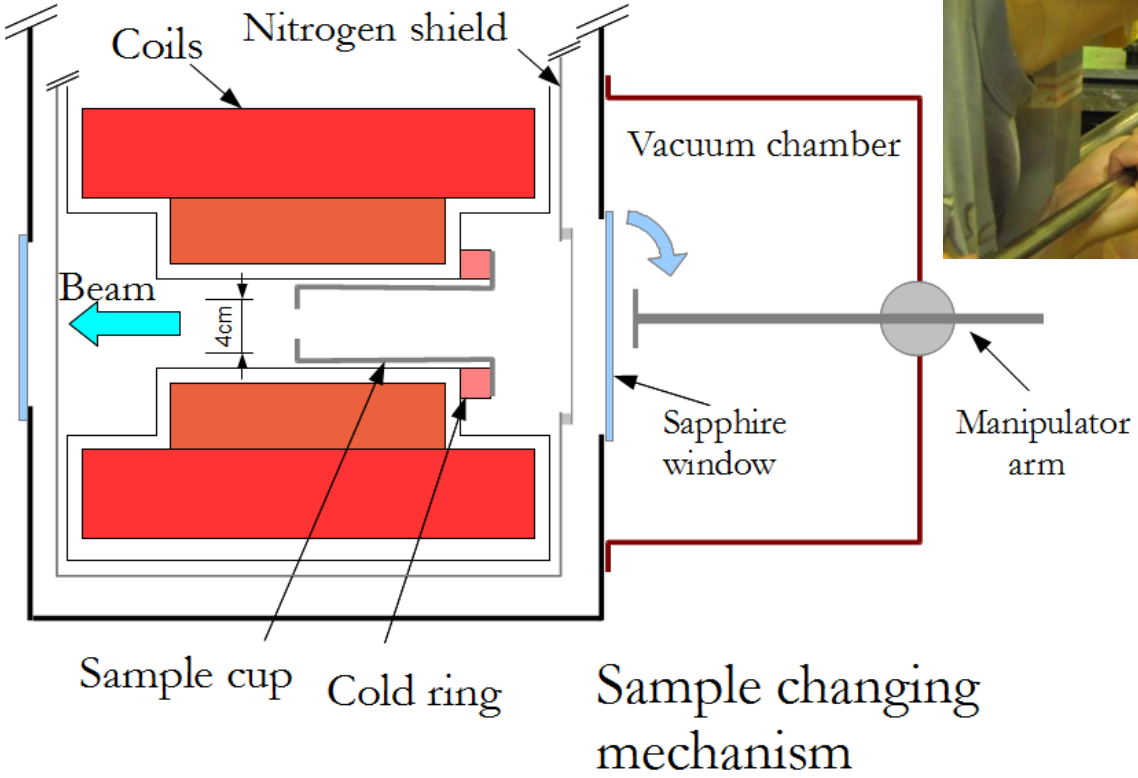


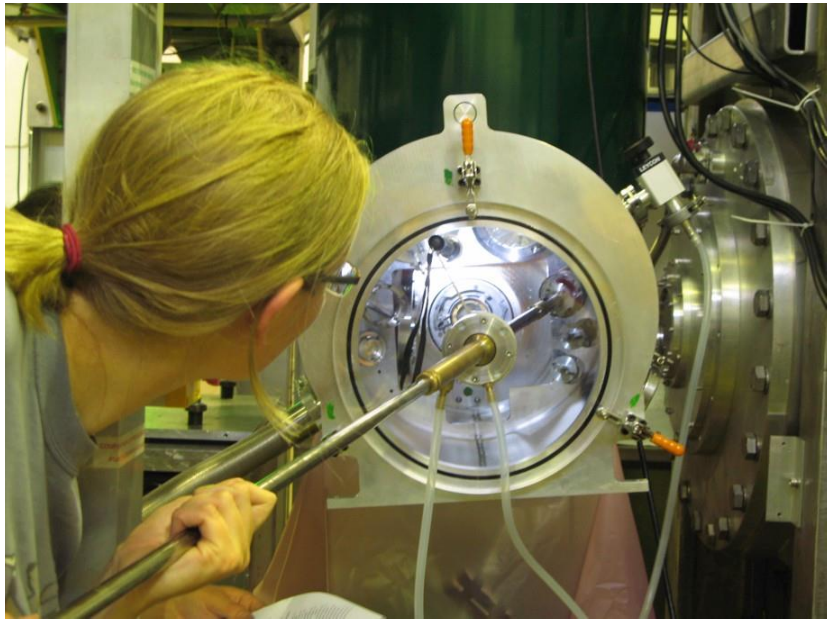



# Horizontal Field Magnet with Conical Bore

UNIVERSITY OF BIRMINGHAM

Sample change is possible with magnet cold



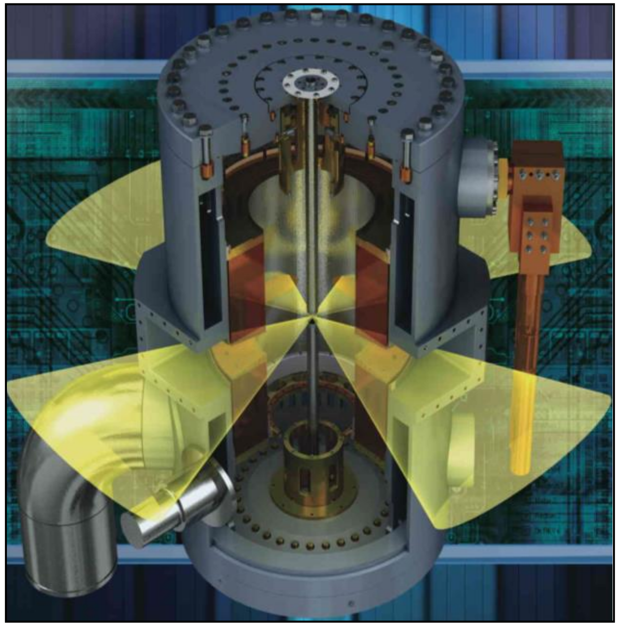



17 T SC Magnet for x-ray or Neutron scattering.

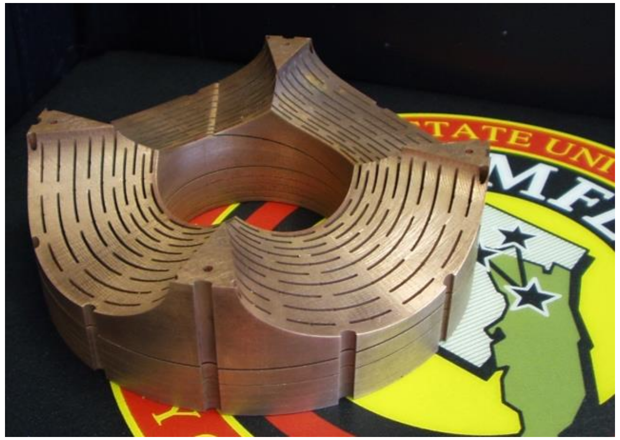
CRYOGENIC
CRYOGENIC LIMITED

# MagLab Split Resistive Magnet: 25 T, 28 MW

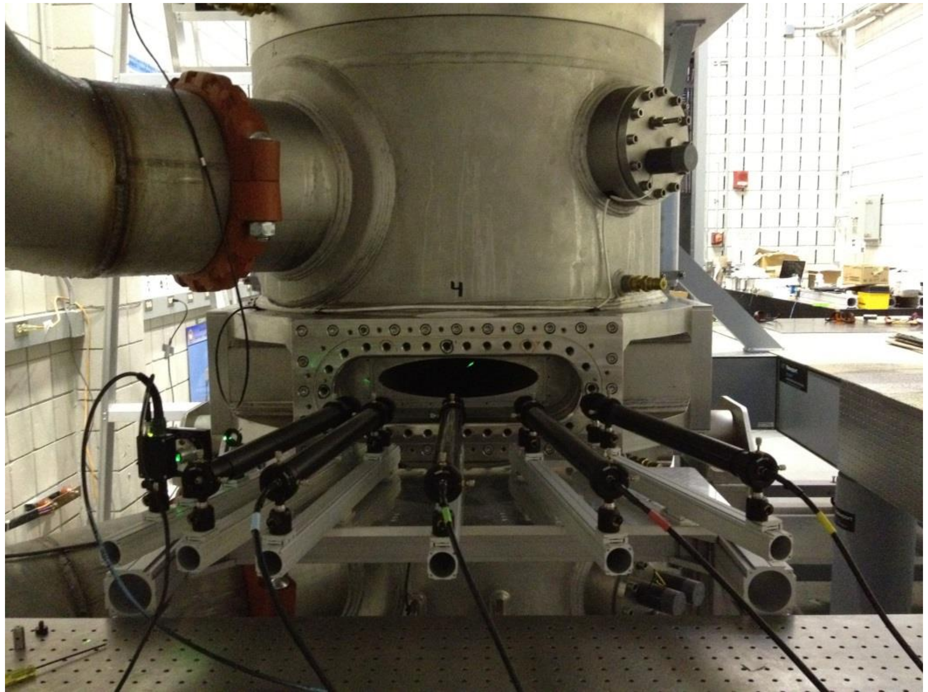
## 4 ports of 45° for fsec Optics, Raman, THz, X-rays



~1m



**June 2011**
**New Technology:**
Split Florida-Helix to wrap coils around vacuum space.



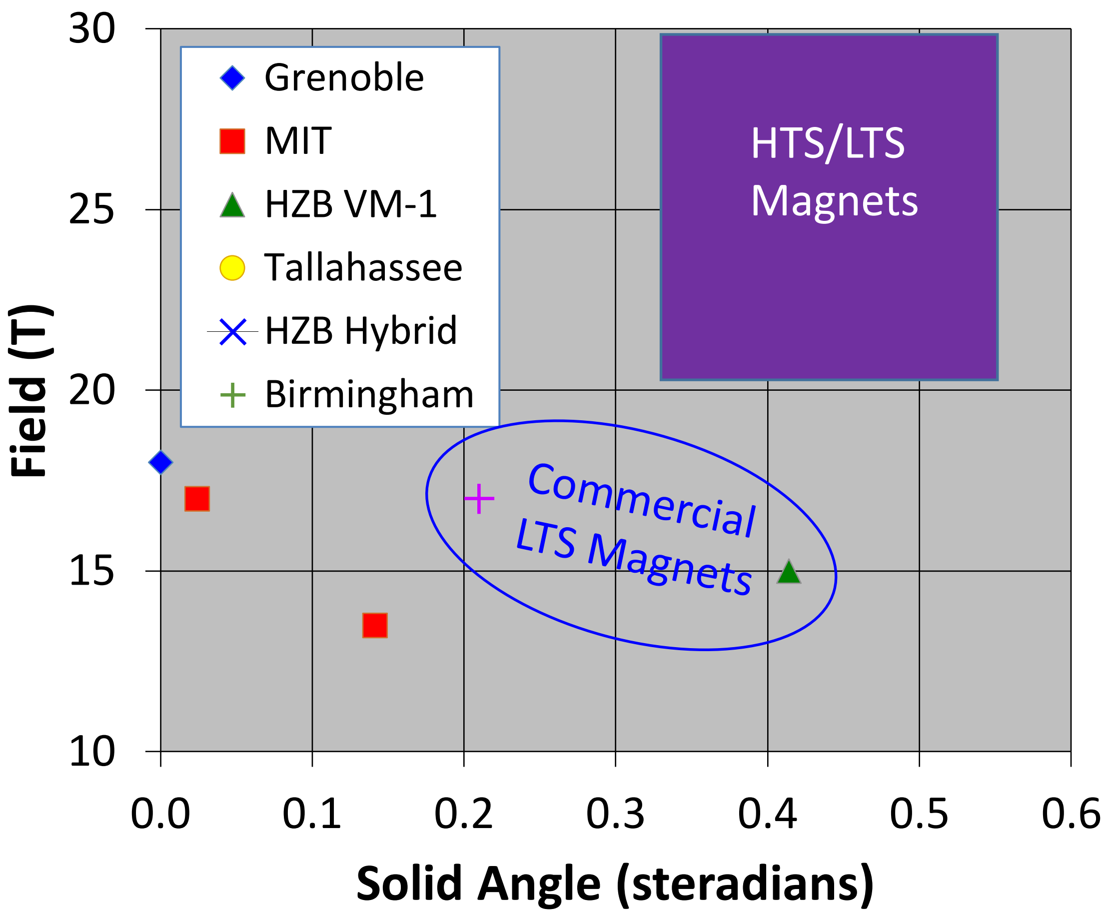
## Operational Since June 2011, Tallahassee

**At the Mid-Plane:**

51% vacuum space. 584 tons of compression.
160 kA of current. 220 l/s of cooling water.
10% steel.

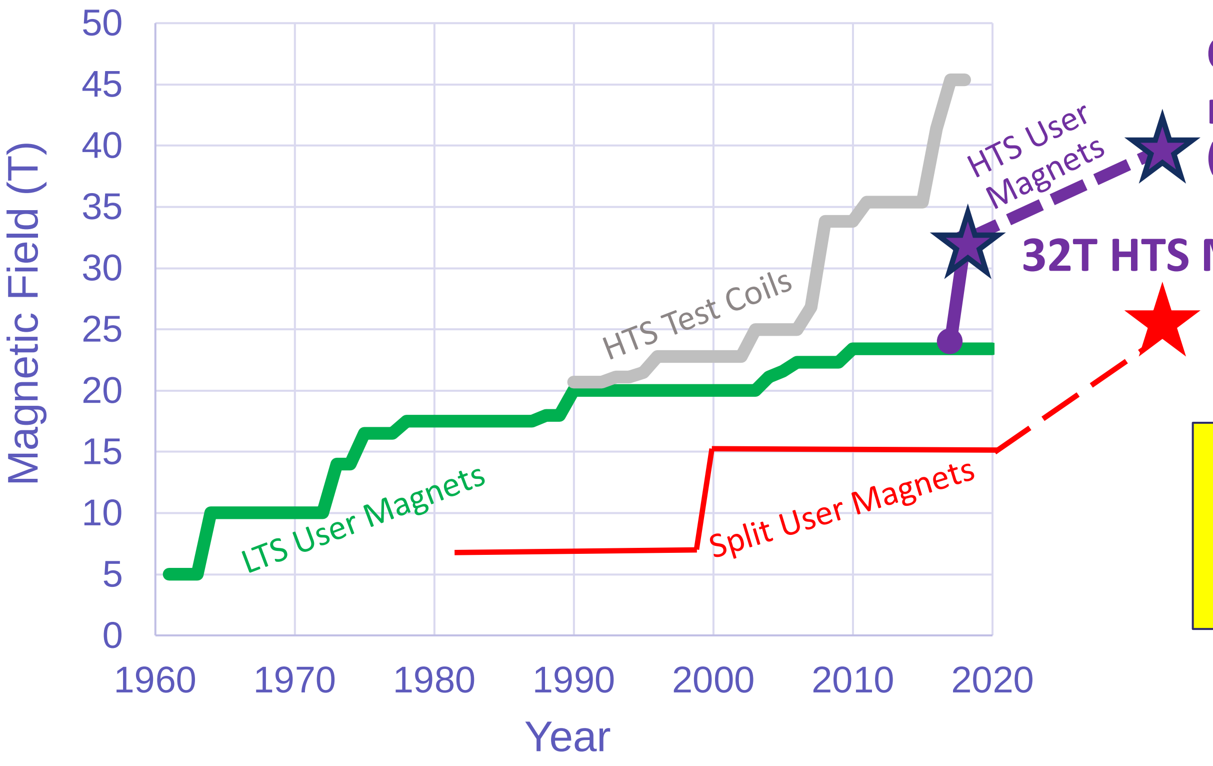
Jack Toth & Mark Bird
Split Magnet Project Managers

# State of The Art for Scattering Magnets




**WHAT SCATTERING MAGNETS SHOULD BE DEVELOPED IN THE FUTURE?**

# High Temperature Superconductors are enabling dramatic increases in magnetic field available from Superconducting magnets!




**Conceptual Design for 40T HTS Magnet now completed by the MagLab**
**(Preliminary Design Underway)**

**32T HTS Magnet now in user service at the MagLab**

**25T HTS Split Magnet proposed for TITAN @ SNS**

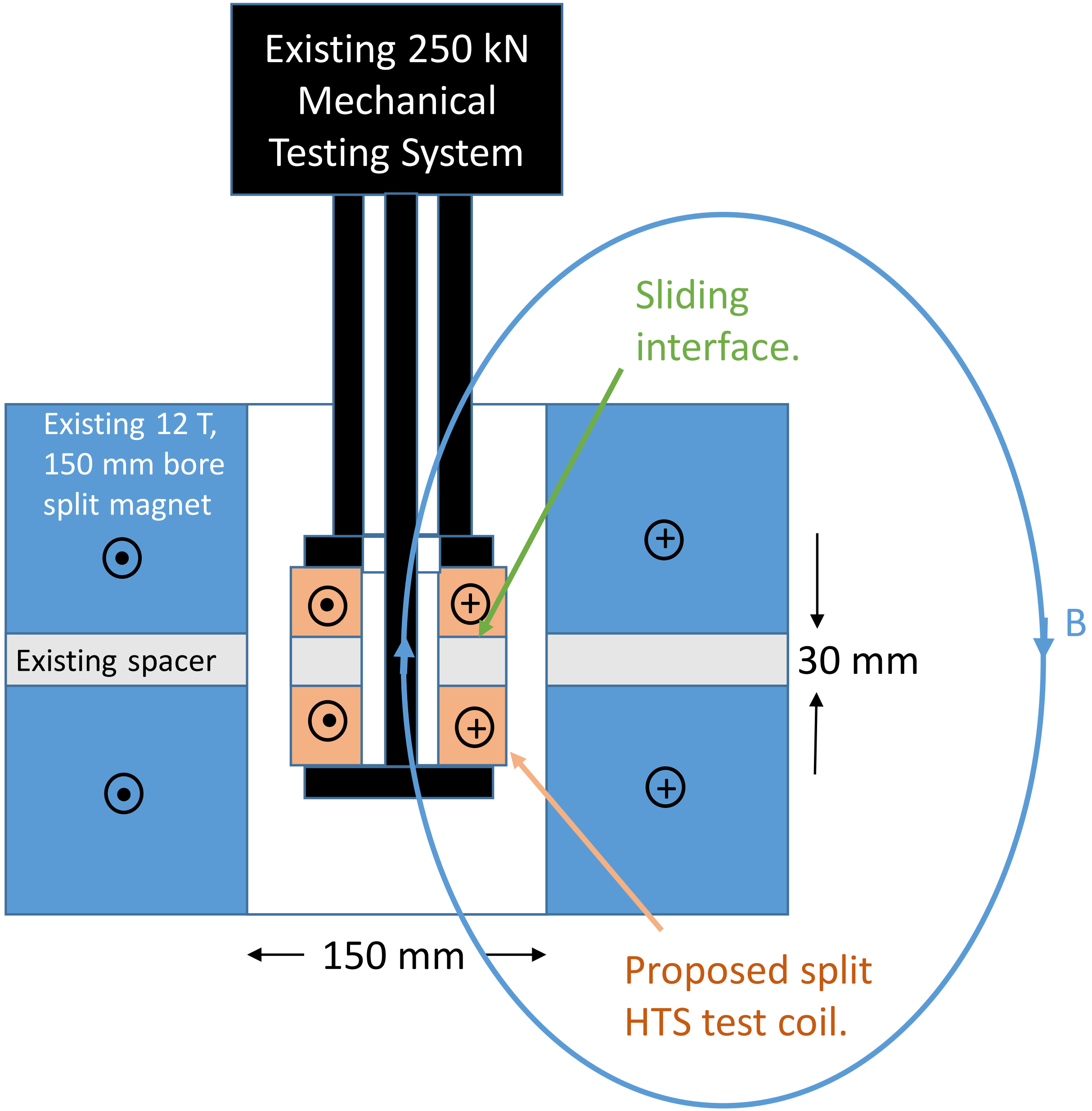
*The time is right to initiate the development of HTS-magnet beamlines for x-ray and neutrons.*

LTS = Low Temperature Superconductor,
HTS = High Temperature Superconductor

## Increases in Superconducting Magnetic Fields Available to Users Since 2016

| Magnet Type | Increase since 2016 | Future Advances Proposed |
|---|---|---|
| **Condensed Matter Physics** | **45%** (32 T at the MagLab) | **82%** (40 T, underway at the MagLab) |
| **Nuclear Magnetic Resonance** | **20%** (1.2 GHz by Bruker) | **30%** (1.3 GHz, underway at both RIKEN and MIT) |
| **Split for Neutron Scattering** | **No increase since 2000** | **67%** (This Proposal) |

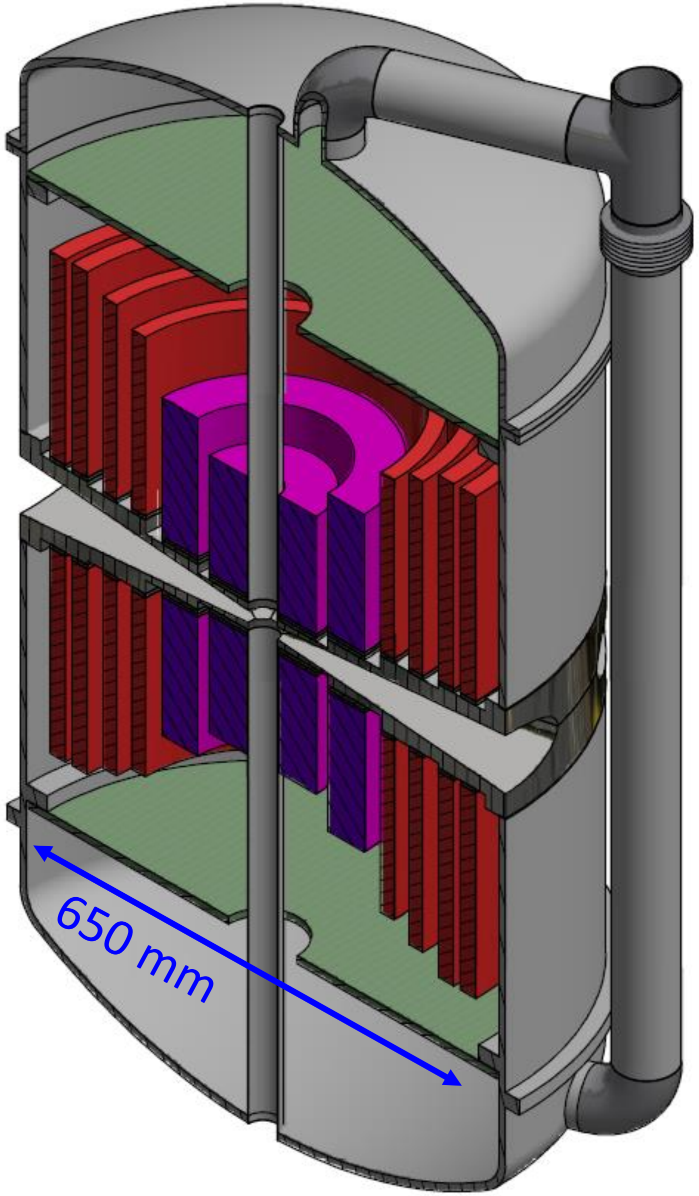
# Development for SNS Split Magnet



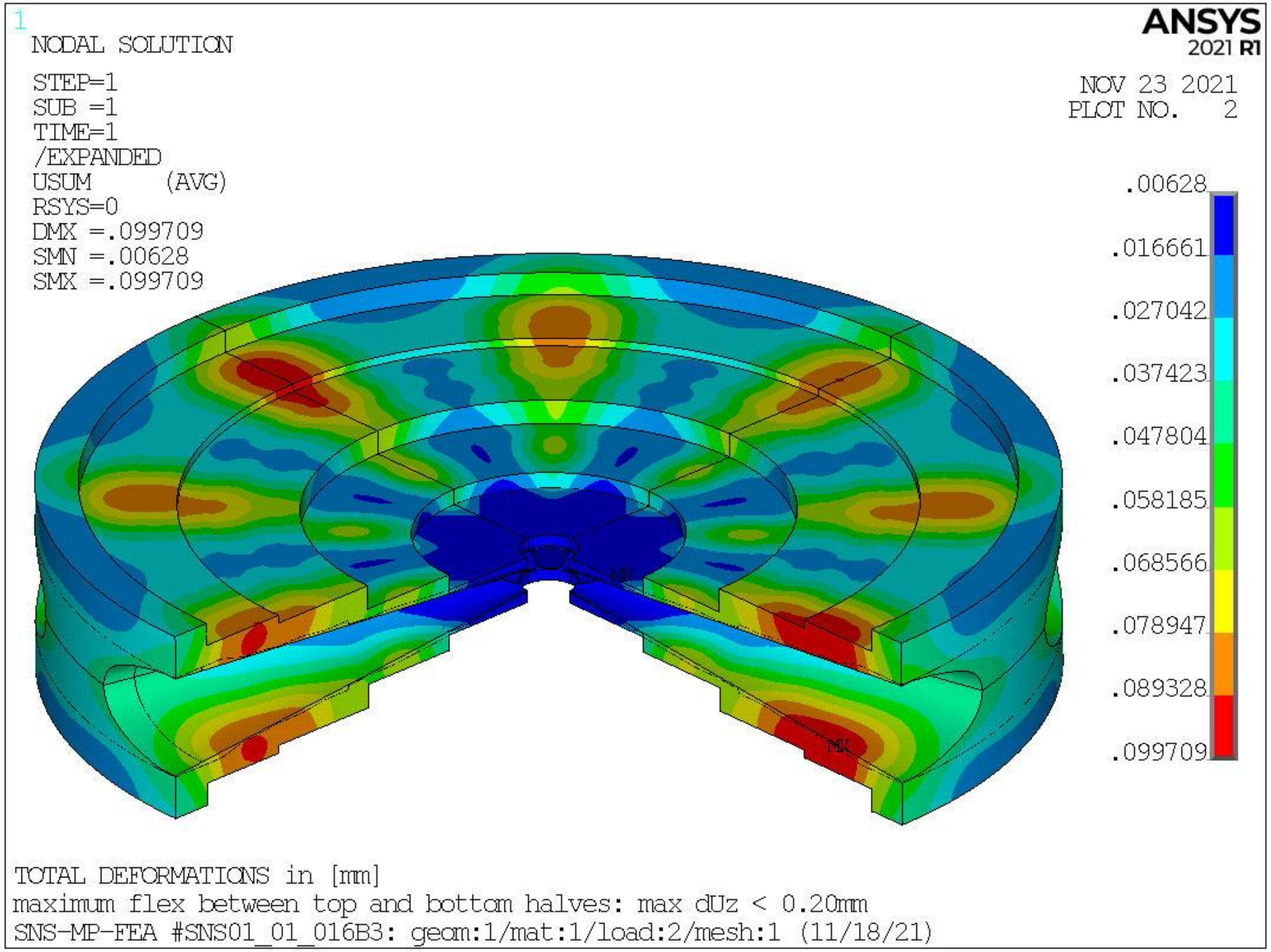

- Built a split HTS coil.
- Installed in existing 12 T split LTS magnet at MagLab.
- Apply cyclic axial compression with MTS machine.

# >20 T Split Magnet Design for Neutrons

## REBCO Tape

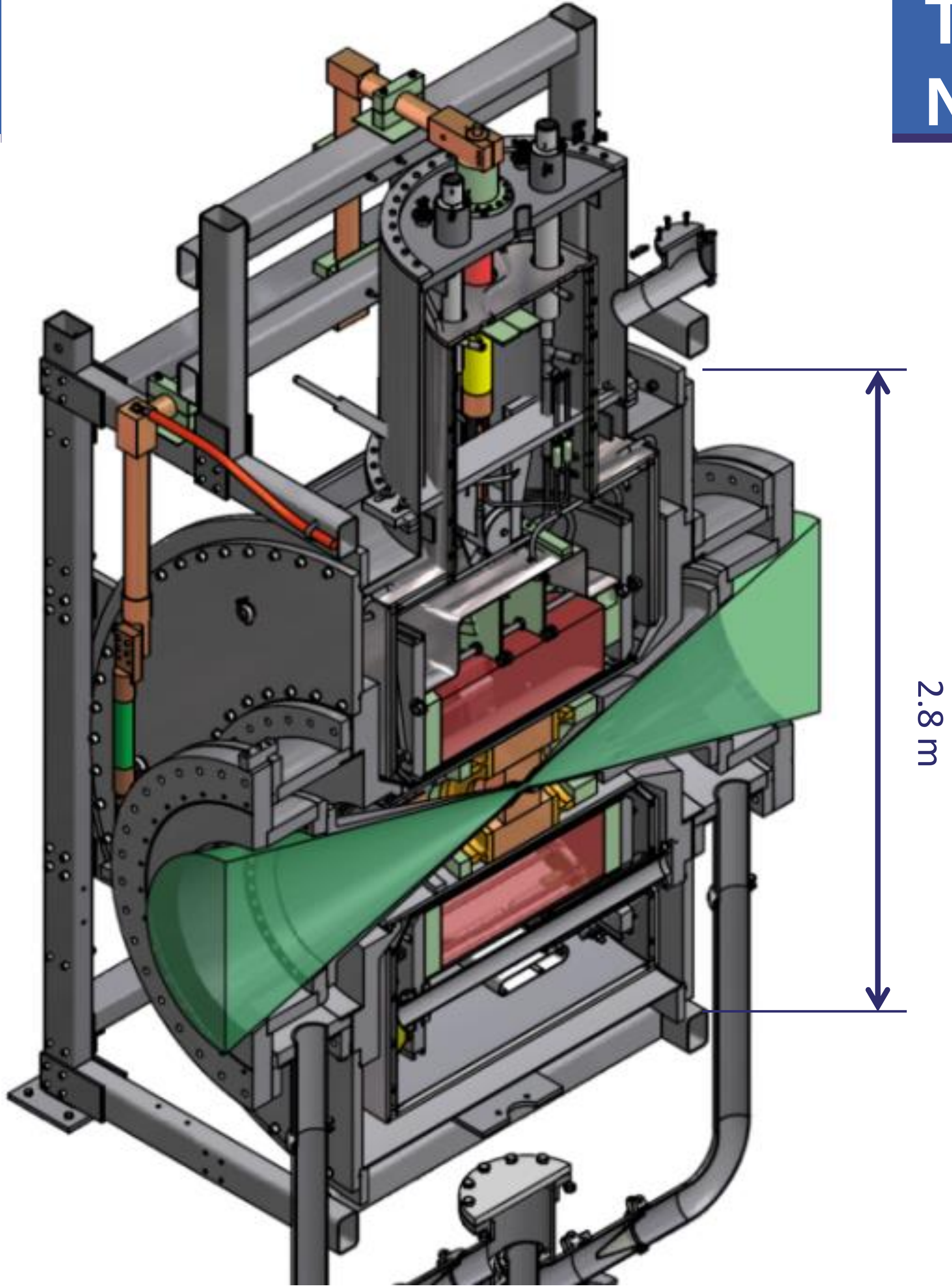



8 ports of 25°




Design Study funded by SNS

# The MagLab/HZB 26 T Magnet for Neutron Scattering



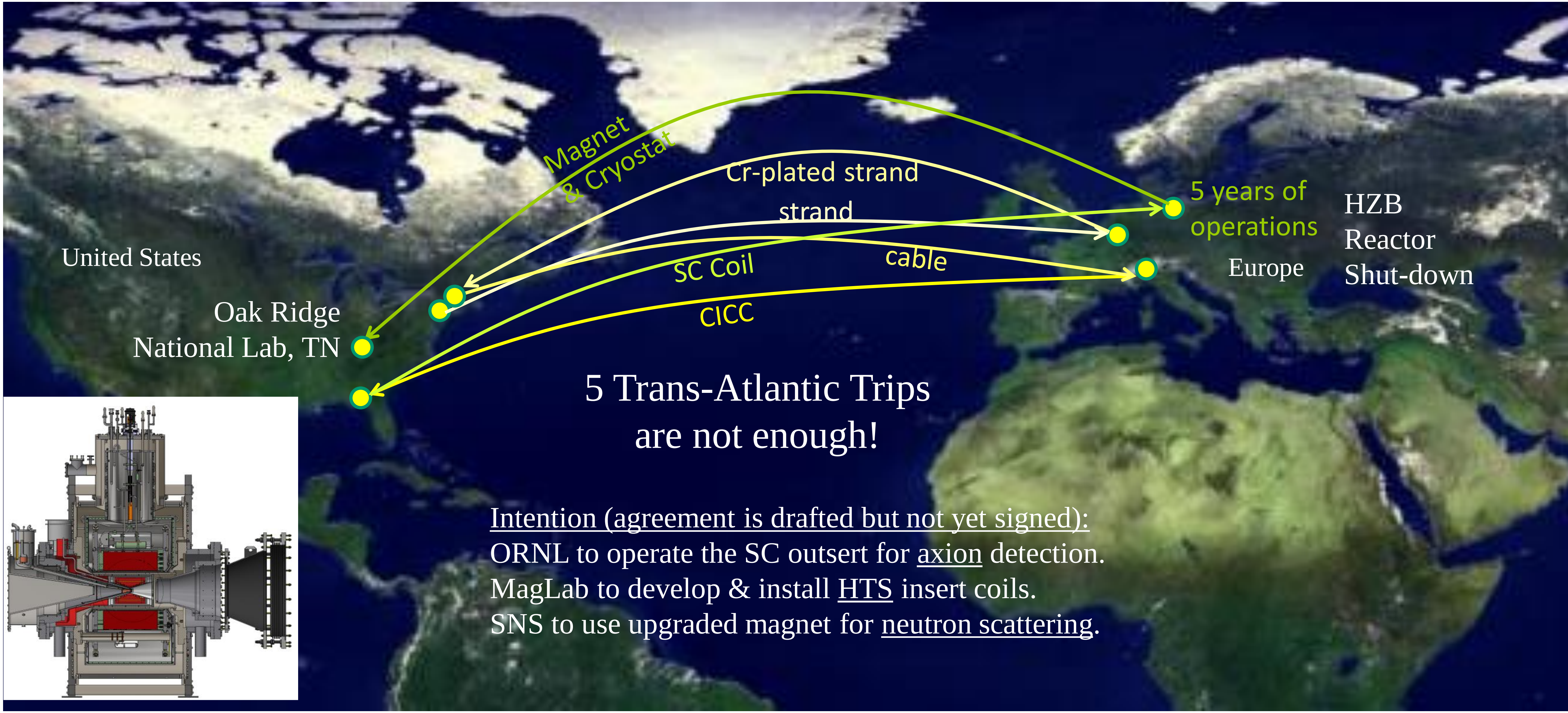

April 2014 Design Review

Highest field magnet worldwide for neutron scattering

Could be upgraded to 30 T with more power.

# The MagLab/HZB 26 T Horizontal Field Magnet's Travel Itinerary

## *Bringing Magnets, Axions, & Neutrons Together.*




5 Trans-Atlantic Trips
are not enough!

Intention (agreement is drafted but not yet signed):
ORNL to operate the SC outsert for axion detection.
MagLab to develop & install HTS insert coils.
SNS to use upgraded magnet for neutron scattering.

# Summary

- There are a number of applications for ultra-high field magnets based on HTS materials other than those the MagLab's user facilities serve.
- Scattering of X-Rays and Neutrons is a field the MagLab has worked in for many years.
  - 25 T vertical split resistive at MagLab (2011)
  - 26 T horizontal conical resistive/superconducting hybrid at HZB (2017)
- Axion detection has become one of the top priorities of the Particle Physics community
- <u>MagSci recommends</u>
  - SC scattering magnets up to 40 T
    - Similar to 40 T SC magnet underway at MagLab.
  - Axion detection magnets
    - Sikivie haloscope is similar to MagLab's 40 T SC,
    - Plasmonic Haloscope is similar to magLab's hybrid outserts