NATIONAL HIGH MAGNETIC FIELD LABORATORY

HTS and Discovery Science

Kathleen Amm, Eric Palm, Mark Bird, Ian Dixon, Lance Cooley, Steven Gourlay, Mark Palmer and many others

U.S. National Science Foundation | FSU FLORIDA STATE UNIVERSITY | UF UNIVERSITY of FLORIDA | Los Alamos NATIONAL LABORATORY

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

Outline

- Intro to MagLab 3.0
- Role of solenoids in discovery science
  - Axion search
  - Neutron source research
  - CHESS
- HTS and Muon colliders
- Impact of HTS discovery science research on HTS conductor development

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

MagLab Vision

Enable the best science and technology in high magnetic fields on Earth and make the world a better place

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

MagLab Mission

We serve the nation and the world by providing access to research in the world's highest magnetic fields and the science and technologies resulting from this research. We do this by

- Operating the world leading high magnetic field user program
- Developing a thriving in-house R&D program and providing an outstanding environment for our employees
- Maintaining and improving the facility and developing new magnets and instrumentation
- Developing all generations of STEM talent and providing outreach and education to the public on the impact of our research

The outcomes are outstanding science and technology and a positive impact on society.

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

NATIONAL HIGH
MAGNETIC FIELD LABORATORY

Magnets Matter

The National MagLab designs and builds the most powerful magnets in the world. Researchers use these unique instruments to make fundamental discoveries that shape our future.

Advancing Human Health

- Imaging biomarkers for cancer, migraines and Alzheimer's
- Probing protein structures for tuberculosis and influenza to design targeted treatments
- Using high field MRI to improve recovery in stroke victims
- Characterizing zero-resistance wires for next-generation MRI technology

Making Materials Discoveries for New Technology

- Searching for new superconductors that could revolutionize energy infrastructure
- Measuring electronic properties of components for quantum computing and devices
- Investigating natural marvels like insect wings and worm slime that could inspire new materials
- Developing nanocomponents to improve processing power and memory for next-gen electronics

Combatting Climate Change & Protecting the Environment

- Analyzing how wildfires, oil spills and other disasters impact our soil, water, and food supply
- Understanding the complex chemical compositions of our rivers, watersheds and oceans
- Unraveling perplexing pollutants found in food packaging, cookware and fabrics

Finding New Energy Solutions

- Exploring ways to design stronger, more efficient batteries
- Examining new biofuels for greener transportation
- Diversifying supply of critical elements to build wind turbines, EVs and other clean energy technologies
- Pioneering powerful magnets to help harness fusion energy

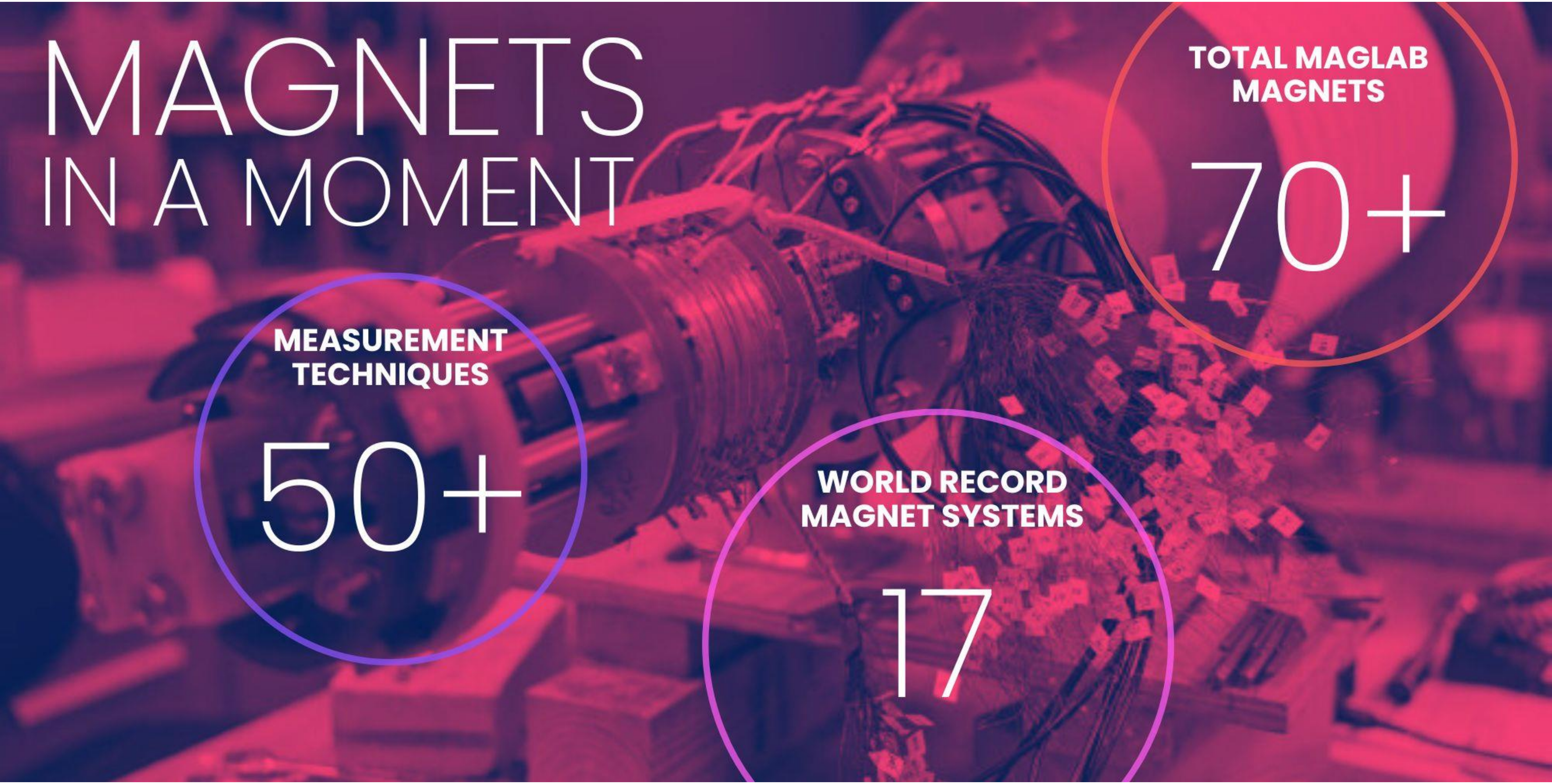
Solving the Mysteries of the Universe

- Analyzing meteors and moon dust for clues about the origin of our solar system
- Pinpointing molecules needed for life in exoplanet atmospheres
- Producing precision magnets for particle colliders

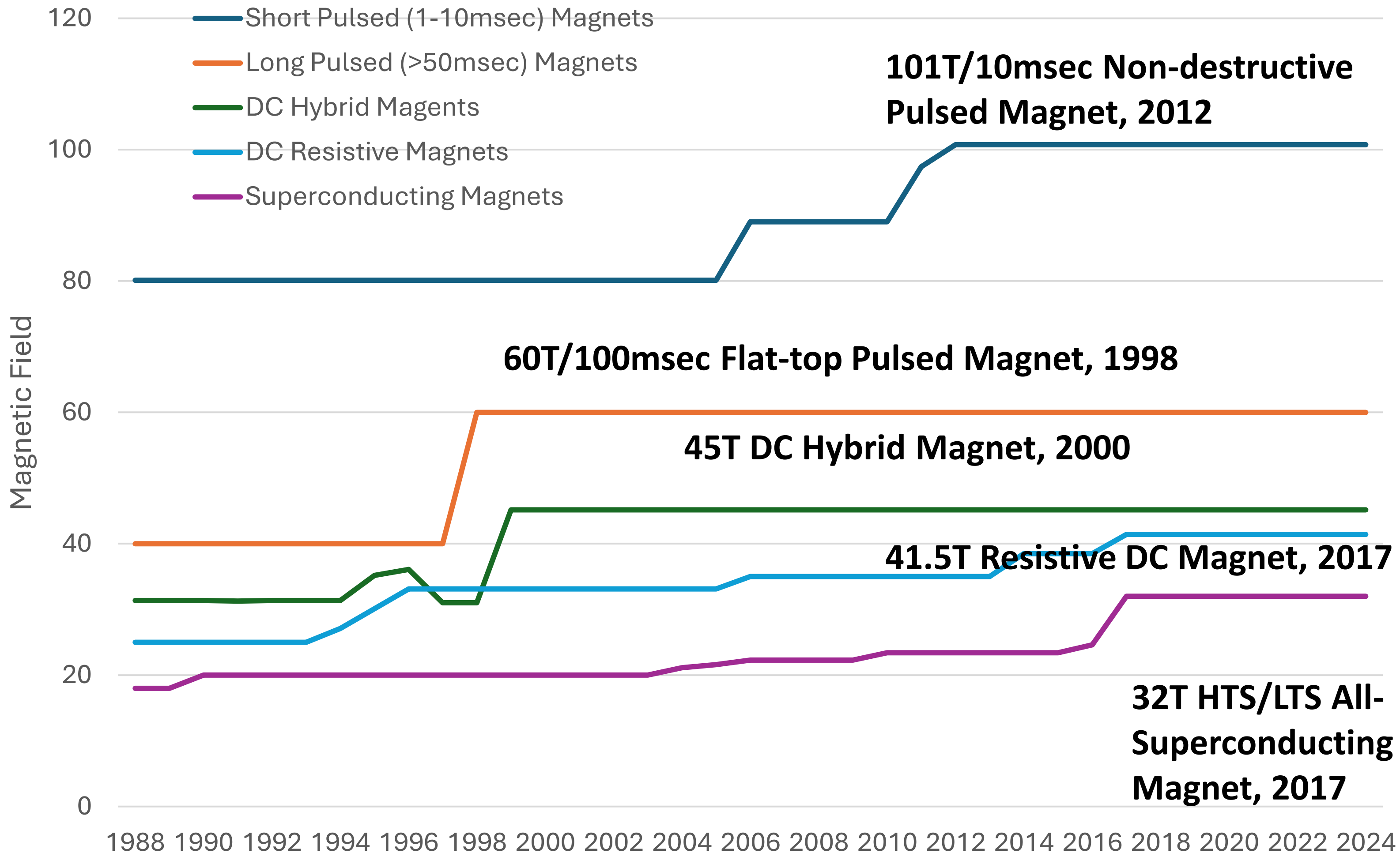
Funded by:

NSF FSU FLORIDA STATE UNIVERSITY

UF UNIVERSITY of FLORIDA Los Alamos NATIONAL LABORATORY


MAGNETS
IN A MOMENT
TOTAL MAGLAB MAGNETS
70+
MEASUREMENT TECHNIQUES
50+
WORLD RECORD MAGNET SYSTEMS
17

Current State of MagLab Magnets



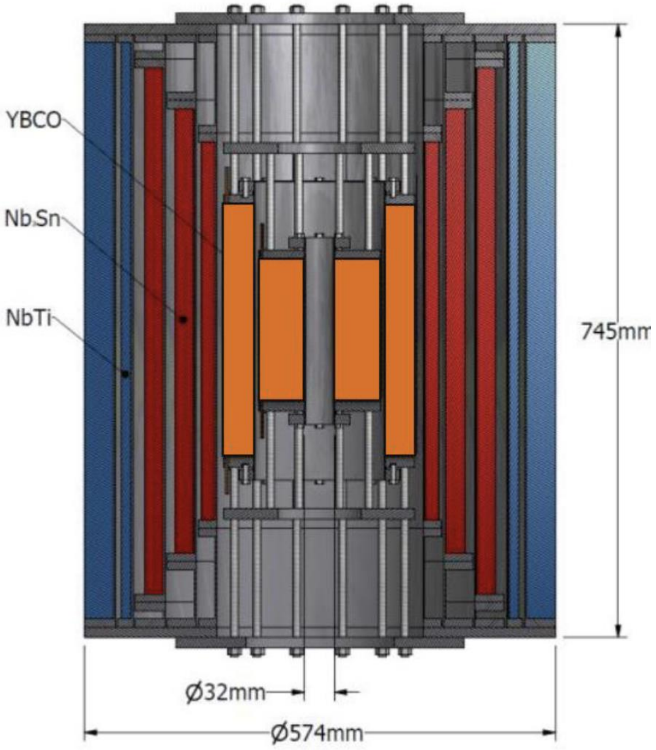
MagLab Records:

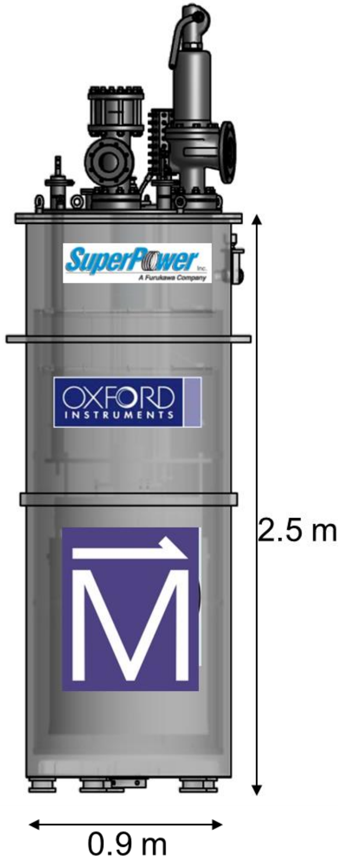
17 World Record Magnet Systems & other specialized flagship magnets:

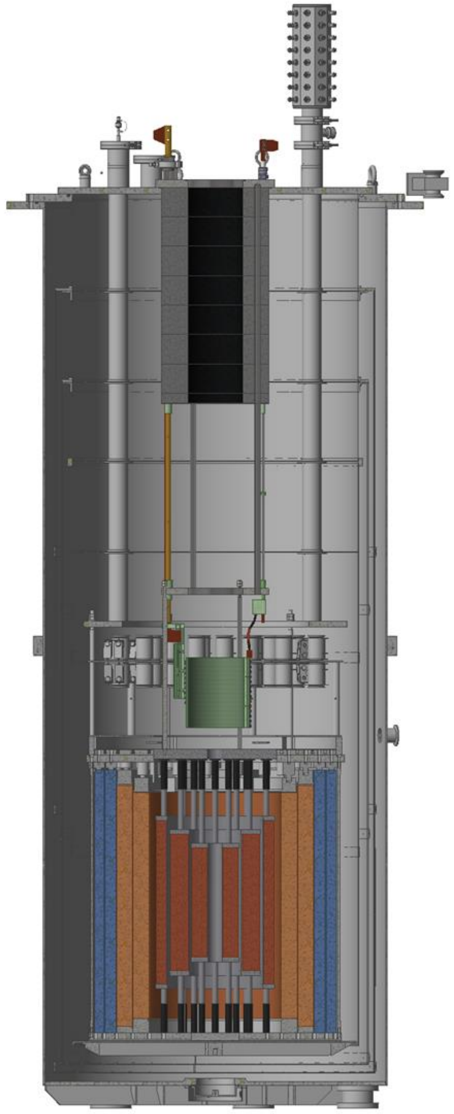
- 101T Pulsed
- 45T Hybrid
- 41.5 Resistive
- 32T All Superconducting
- 21.1T NMR/MRI
- 36T Series Connected Hybrid
- 21.1T FT-ICR
- 85T DUPLEX

Highest field HTS/LTS hybrids – pushing technology for multiple applications

Cross section of **32 T** (15 T LTS, 17 T two ReBCO double pancake coils), **32 mm** user facility solenoid
https://nationalmaglab.org/user-facilities/dc-field/magnets-instruments/







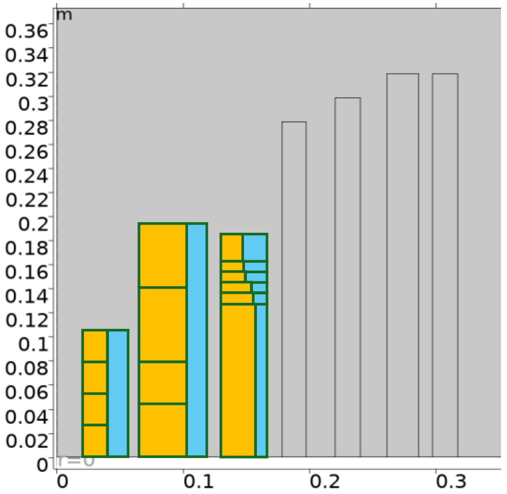
40 T magnet cross section

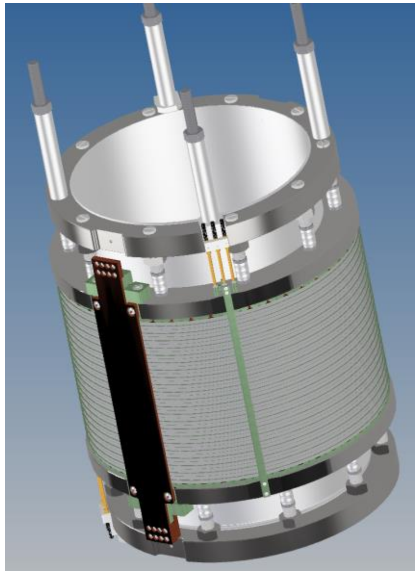
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

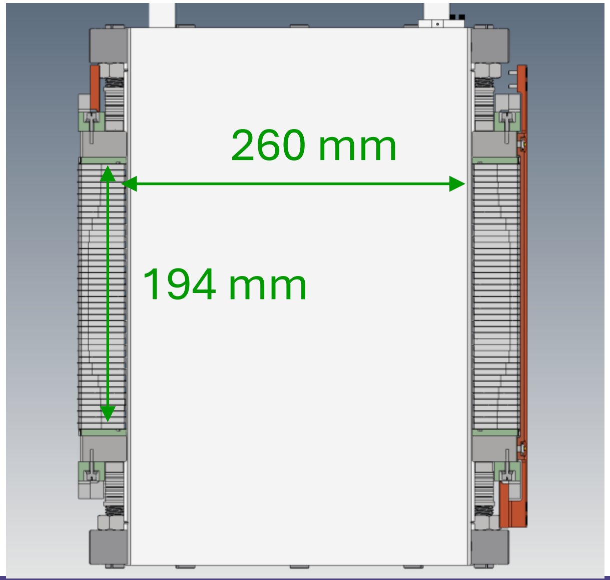
MagLab Strategic Priority: 40 T class, 34 mm bore all-SC magnet

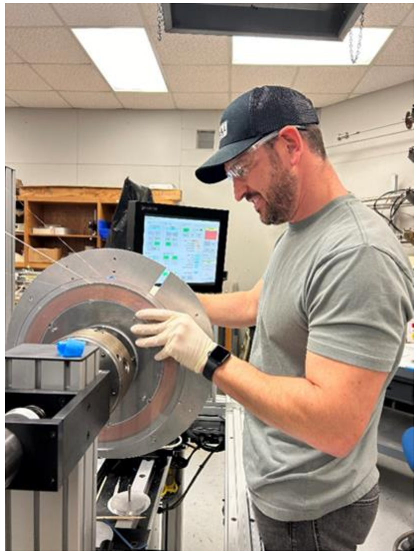
Large Scale test Coil (LSC)

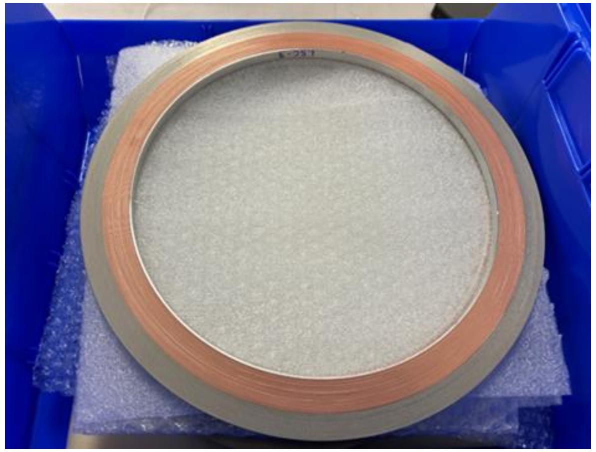
- The updated 40 T class design defined the requirements for the Large-Scale test Coil.
- 250 mm bore, 15 T strength field inside of a 45T outsert
- Coil is half-height of 40 T insert design Coil 3
- Designed to same strain and Ic fraction as 40T insert design
- Has been tested last week











See Ian Dixon's talk from 32 T to 40 T
Wed. at 11:20

2024 National Academy Report

- Released in August 2024
- 13 total recommendations
  - Nearly all call for **jointly-funded** support for high magnetic fields including **partnerships** between NSF, DOE, NIH, and DOD.
    - One recommendation on helium recommends work with the Dept of Interior or Department of Commerce.
  - Acknowledges huge investments in NMR in Europe, Condensed Matter/Materials Science in China.

"The Current Status and Future Direction of High-Magnetic-Field Science and Technology in the United States" (2024)

Synergies to drive progress

- More jointly funded projects are needed to drive the discovery efforts forward
- Budgets for discovery projects in the future are extremely challenging
- Efforts must not just leverage prior work but develop strategic partnerships
- Examples exist – fusion and accelerators

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

Grand Challenges – High Fields

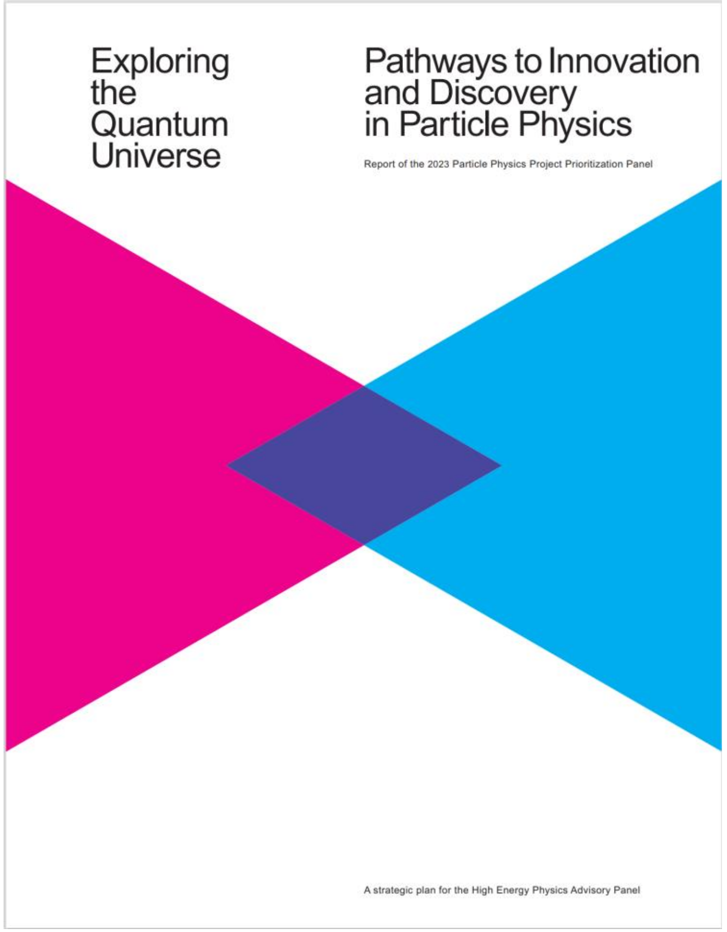
The US National Academy of Science appointed a committee "to identify scientific opportunities and key applications for high-magnetic-field science for the next decade and beyond"

Type	Key Recommendations
Condensed Matter Physics	Develop 60 T hybrid magnet.
	Develop 120 T pulsed magnet.
	Combine high field magnets with x-rays, & neutron-scattering.
Chemistry	Develop 40 T (1.7 GHz) SC magnet for solid-state NMR.
Chem/Bio	Install multiple 1.0 – 1.2 GHz NMR magnets.
Biology	Develop 28 T magnet for small animal MRI.
General	Develop 14 T, 90 cm, >5 T/s HTS magnet.
	Fund operations of user facilities.
	Train personnel at all levels to work in this field.

The "HighMag" Report was published in 2024

Grand Challenges – Particle Physics

In 2021 the European Laboratory Directors' Group published an Accelerator R&D Roadmap to meet the goals laid out previously by the 2020 European Strategy for Particle Physics.



In 2023 the US Particle Physics Project Prioritization Panel (P5) published "Pathways to Innovation and Discovery in Particle Phsysics"

Areas where high field solenoid development can impact discovery areas

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

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.

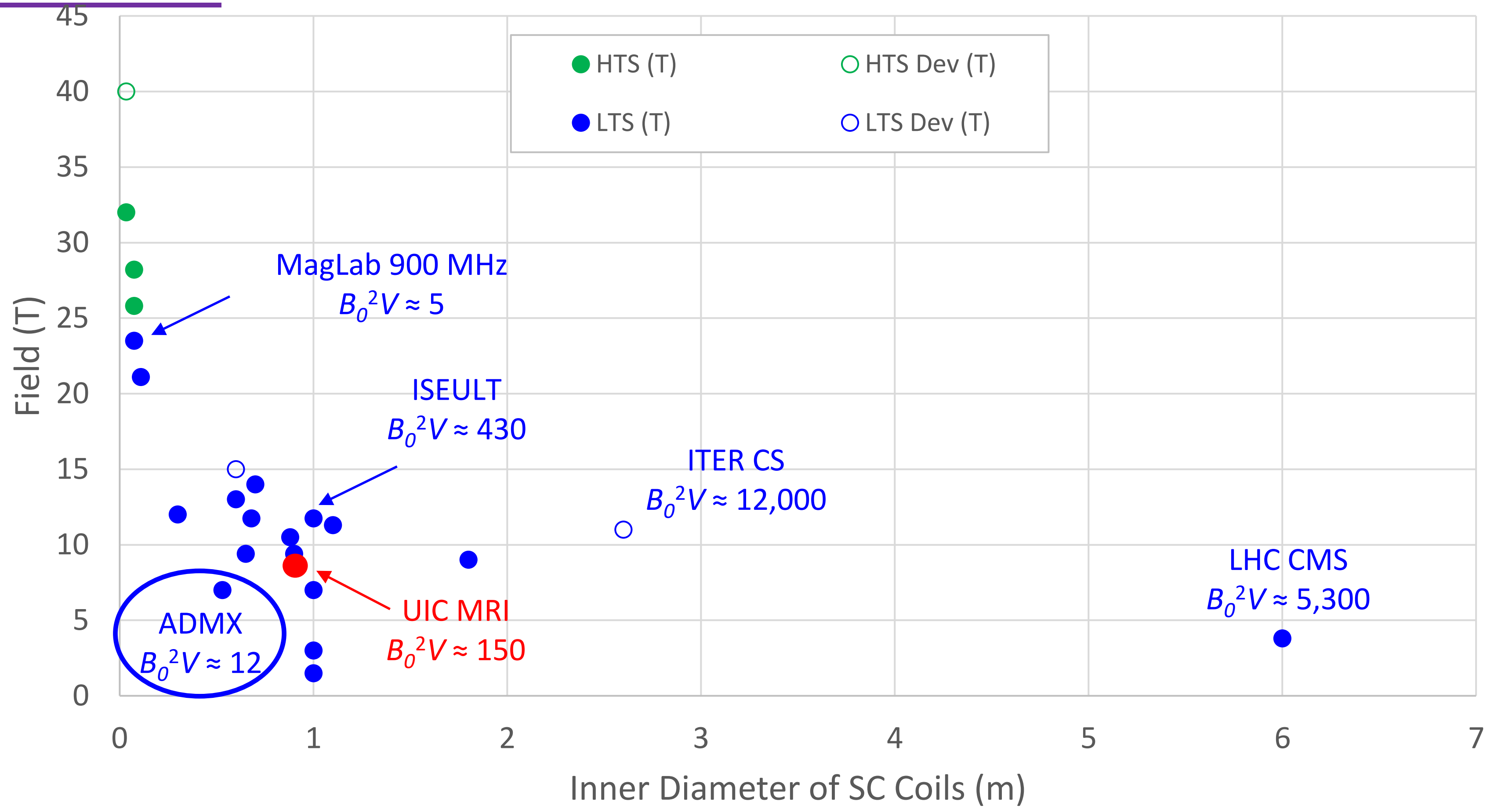
- The Power of axion detectors is given:

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

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



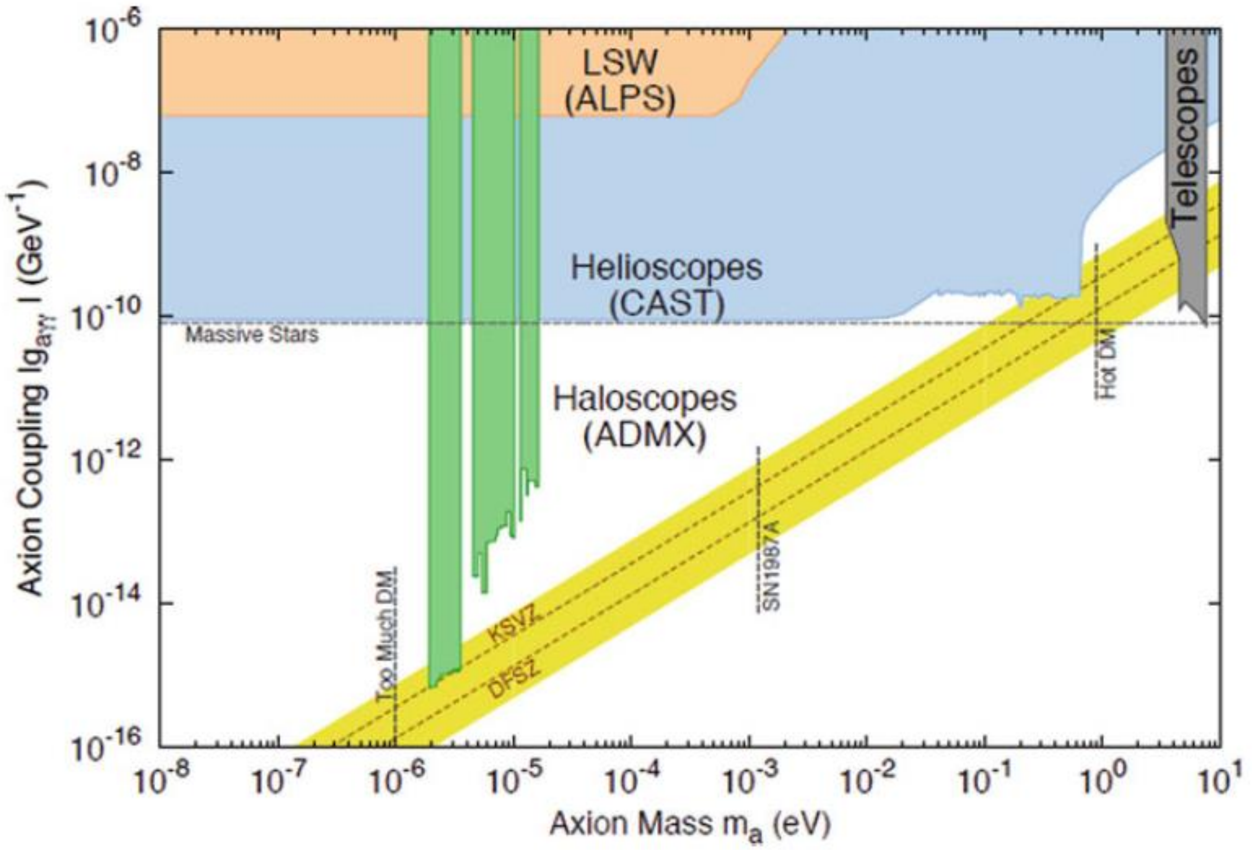
To maximize B_0^2V: ITER CS (11 T, 2.6 m, ~12,000 T^2m^3).

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.

<u>Diameters of ADMX rf cavities</u>

Existing cavity	0.40 m
Cavity required for next octave	0.07 m

We can only slave a few cavities together.

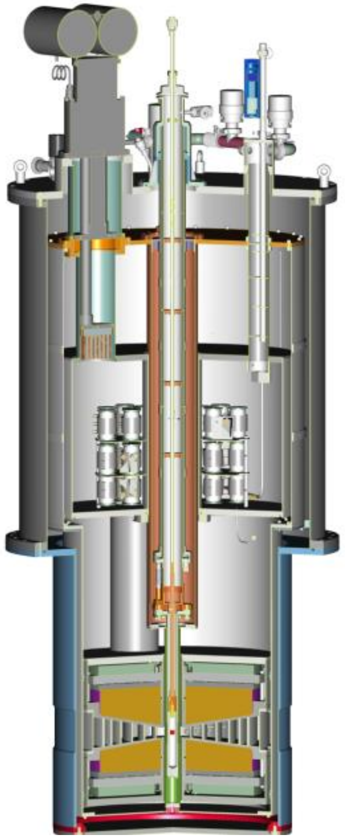
Next generation magnet for ADMX should have a bore of ~0.15 m with as high a field as possible (~30 T?). <u>Similar to 40 T scale project.</u>

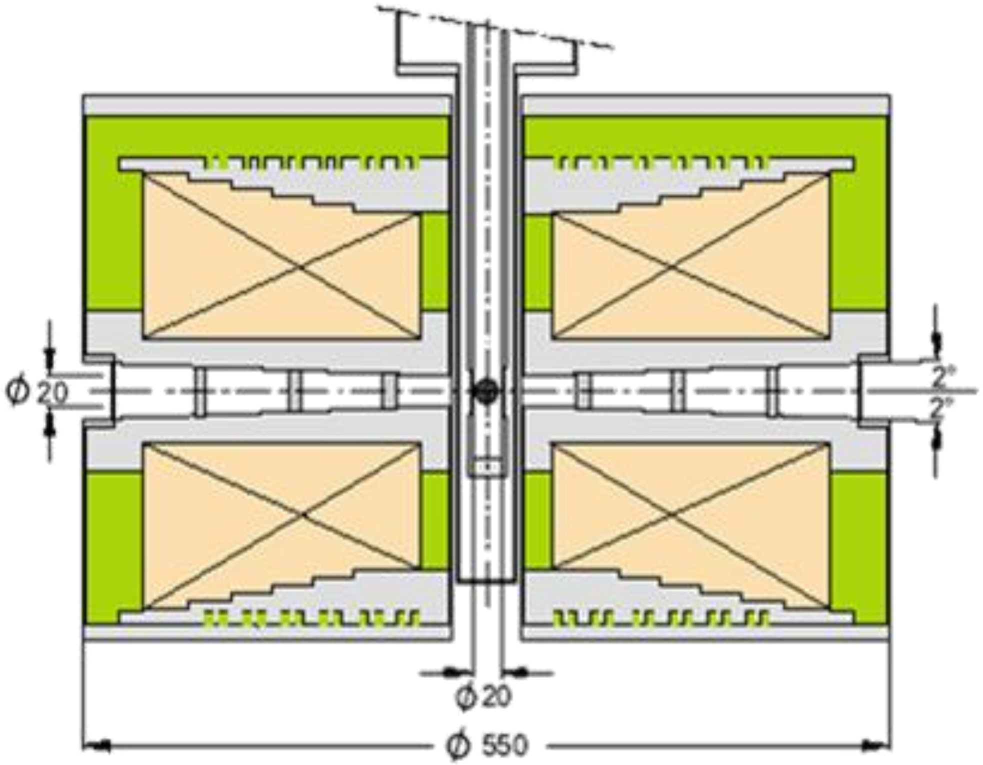
Carosi & Rybka, eds., *Microwave Cavities and detectors for Axion Detection,* (202)

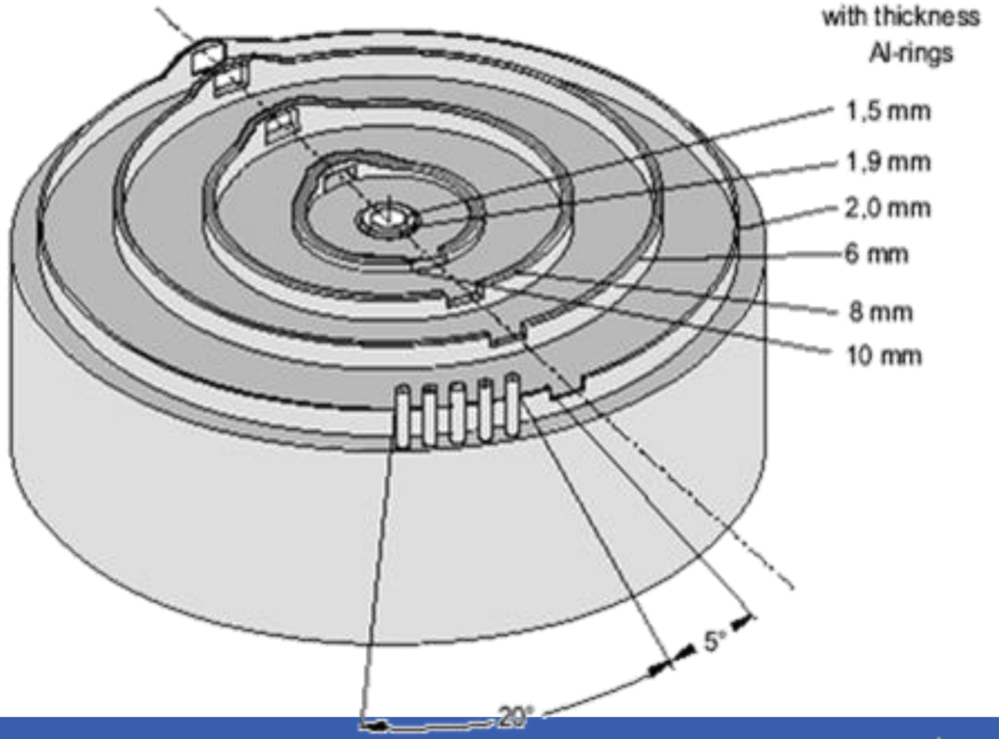
15 T SC Vertical Field Split-Pair

HZB Helmholtz Zentrum Berlin

OXFORD INSTRUMENTS

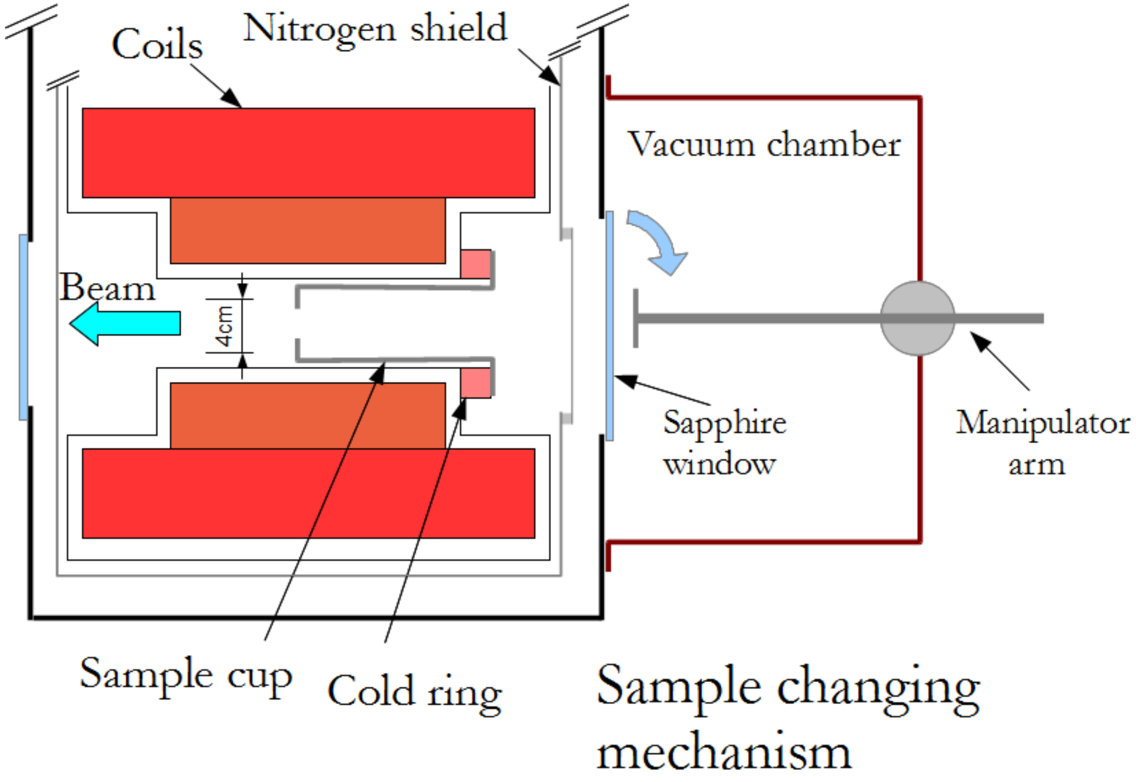


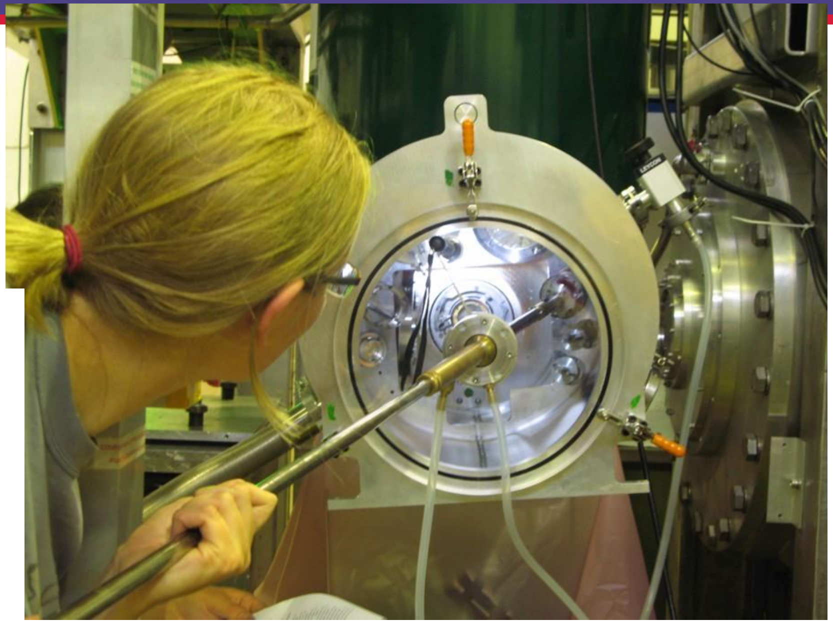




Horizontal Field Magnet with Conical Bore

Sample change is possible with magnet cold



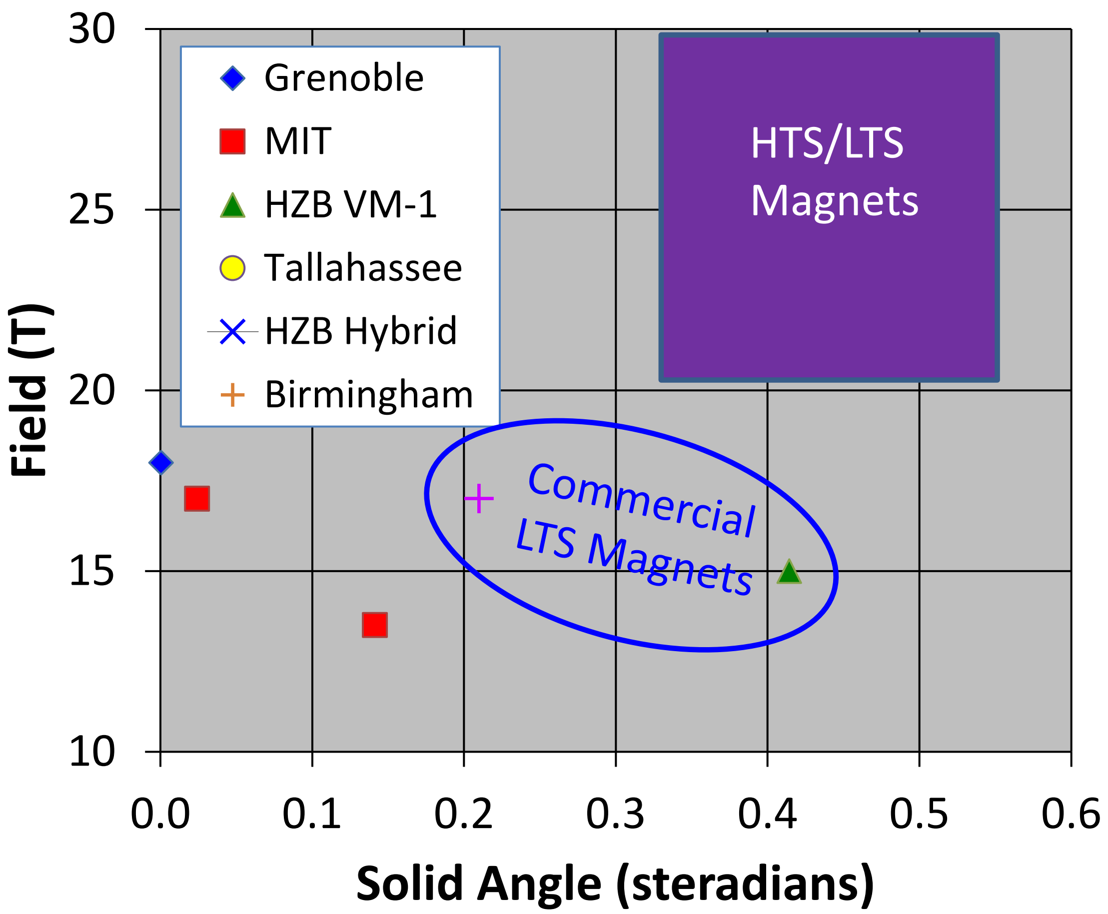


UNIVERSITY OF BIRMINGHAM

CRYOGENIC
CRYOGENIC LIMITED

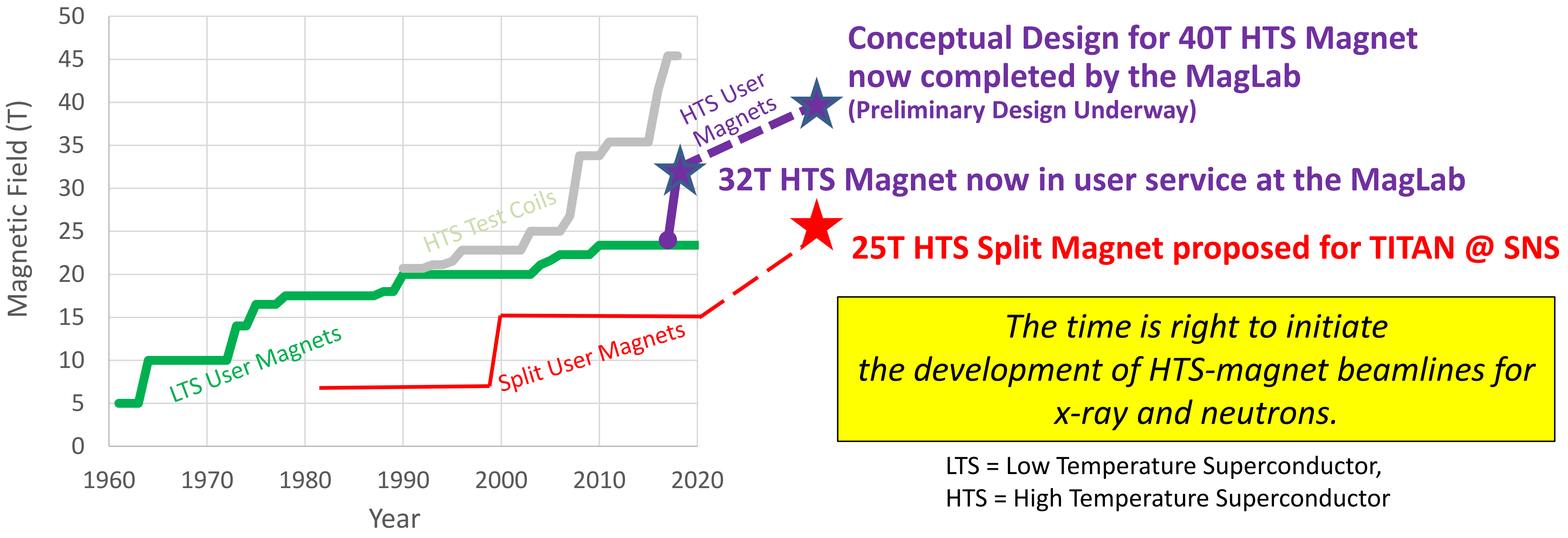
17 T SC Magnet for x-ray or Neutron scattering.

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!



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

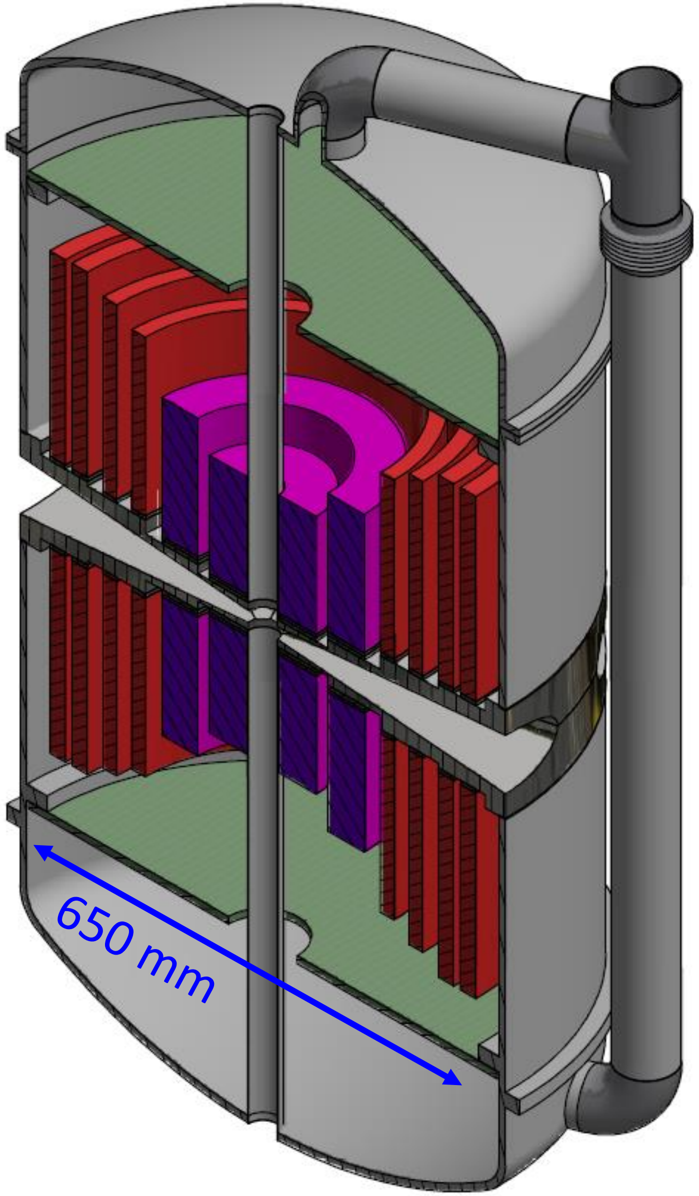
LTS = Low Temperature Superconductor,
HTS = High Temperature Superconductor

Increases in Superconducting Magnetic Fields Available to Users Since 2016

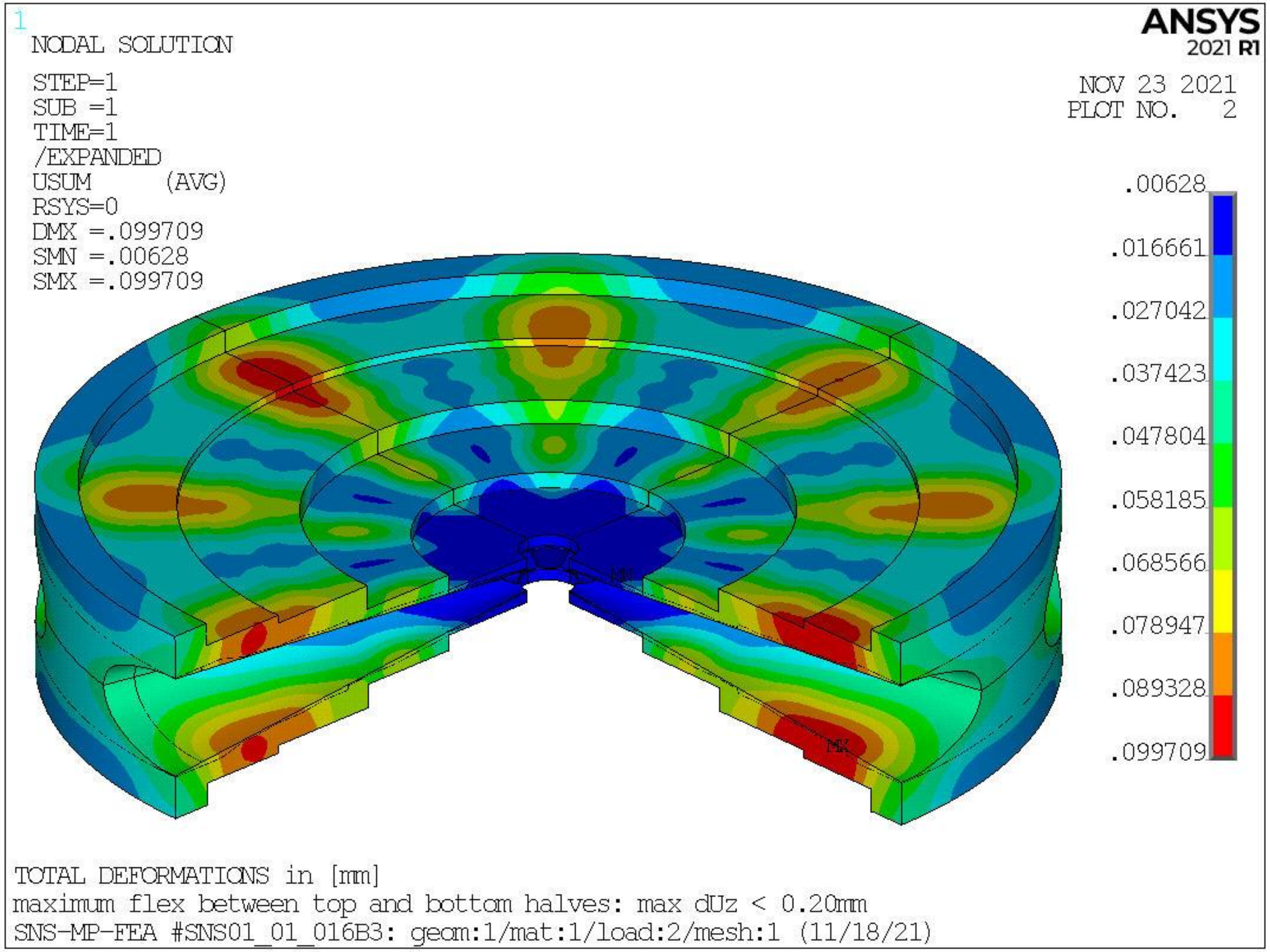
Magnet Type	Increase since 2016	Future Advances Proposed
Condensed Matter Physics	45% (32 T at the MagLab)	82% (40 T, underway at the MagLab)
Nuclear Magnetic Resonance	20% (1.2 GHz by Bruker)	30% (1.3 GHz, underway at both RIKEN and MIT)
Split for Neutron Scattering	No recent increase	67% (Future possibility)

>20 T Split Magnet Design for Neutrons

REBCO Tape

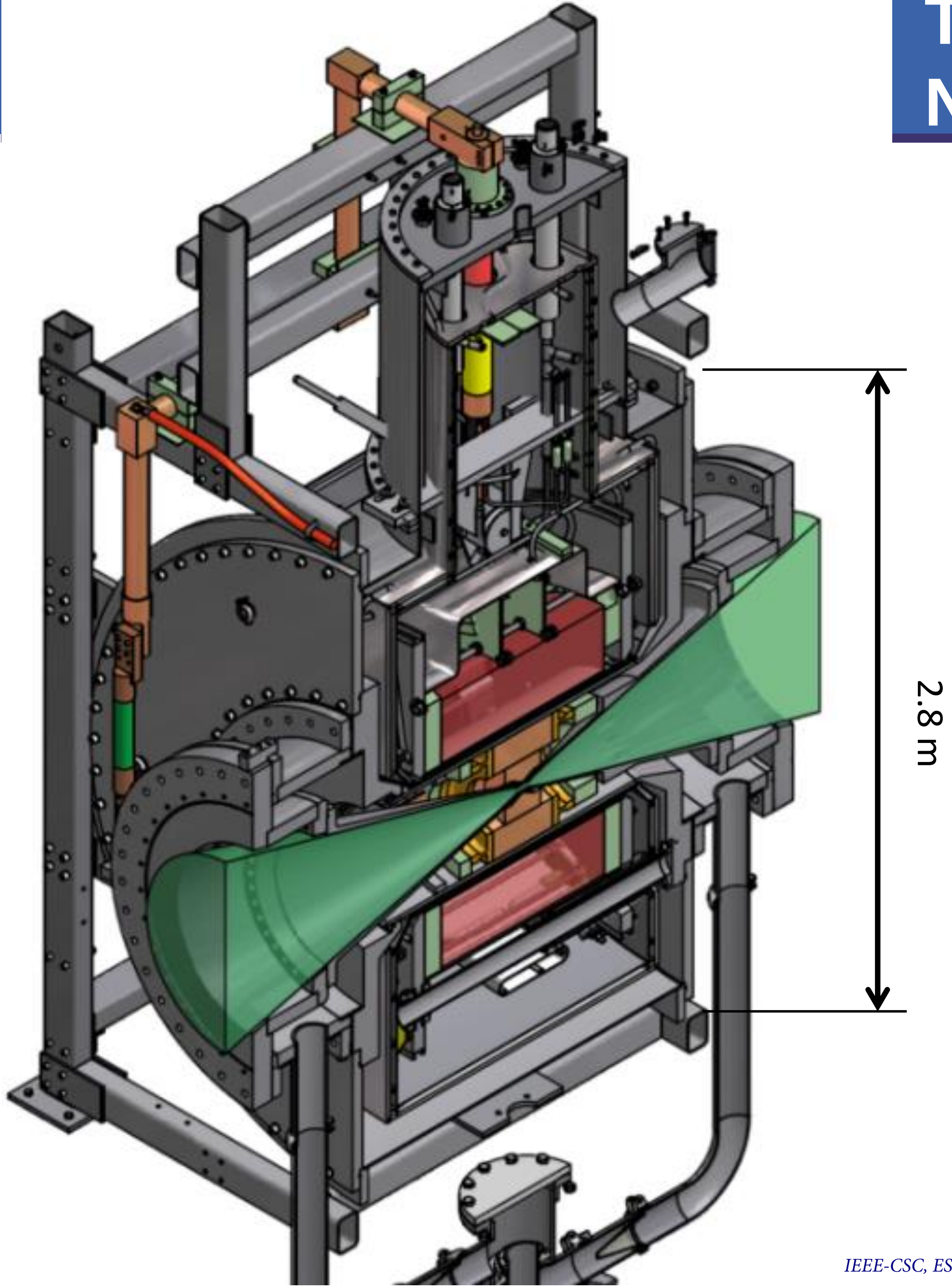


8 ports of 25°



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

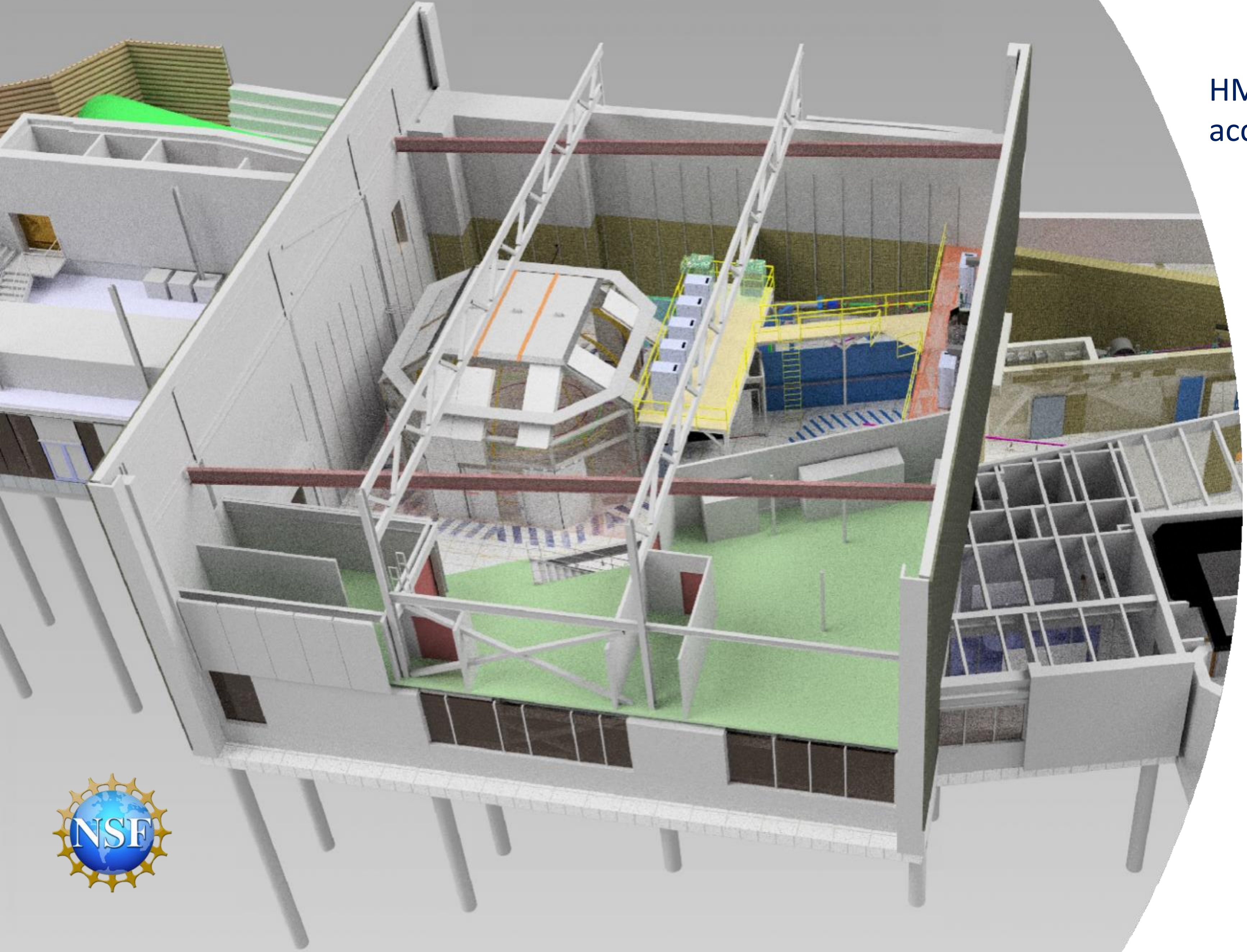
Could be upgraded to 30 T with more power.

HZB Magnet future

- The HZB magnet is now at ORNL
- ORNL and FSU are under discussions on how to best utilize this magnet
- Potential platform for future HTS neutron scattering magnets

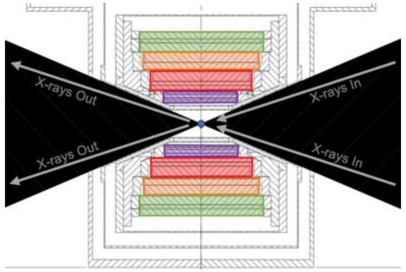
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

The High Magnetic Field (HMF) Beamline at CHESS



HMF features high continuous magnetic field (20 Tesla)

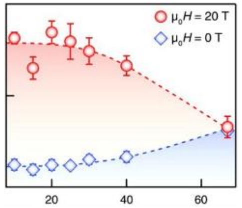
HMF conical solenoid features wide optical access for experiments (50 deg)



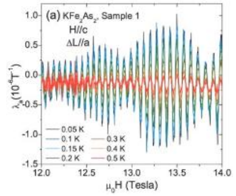
HMF Science Drivers

(1) Spin structures in high fields

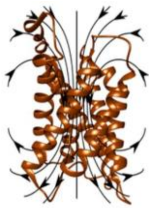
(2) Broken symmetries of electronic quantum matter



(3) New probe of 3D Fermi surfaces



(4) New tuning parameter for structural biology

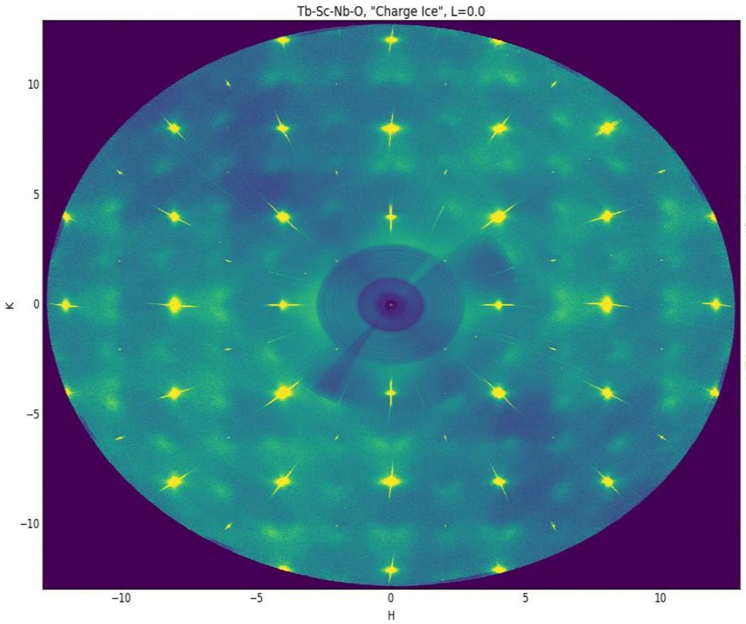


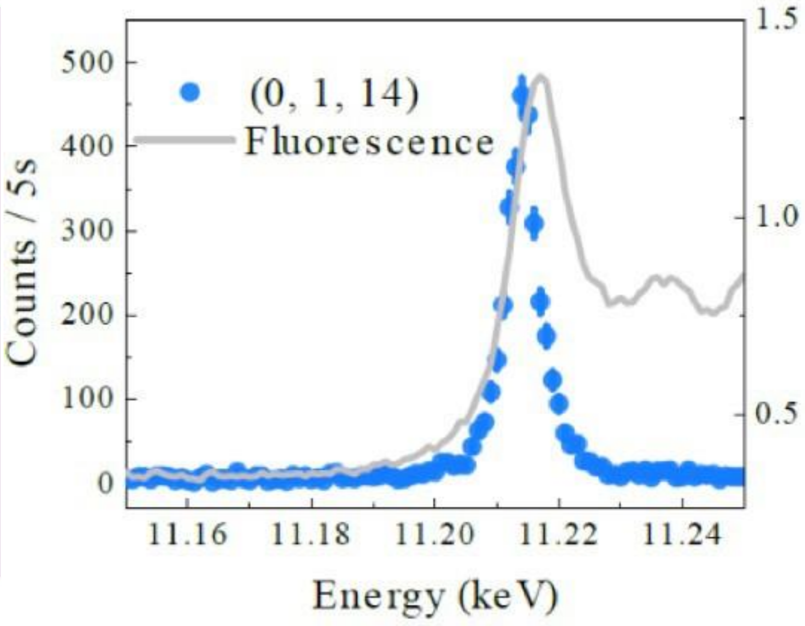
(5) Controlling processes in engineering and chemistry

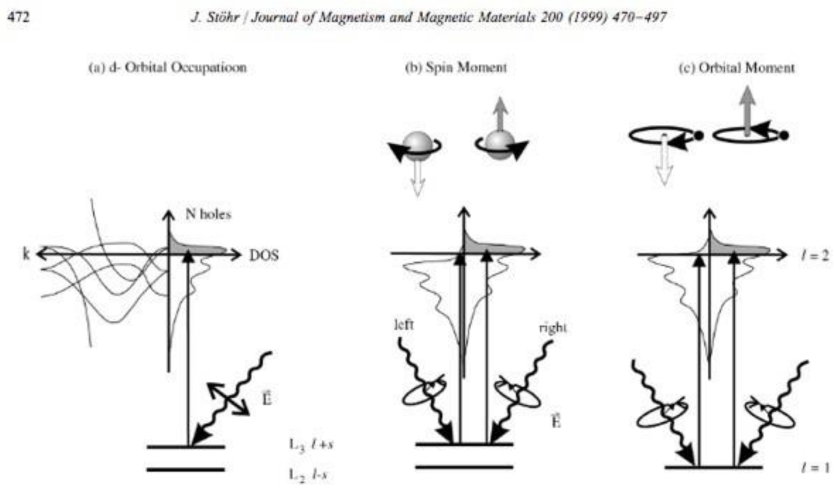
Synchrotron X-rays Enabling Discovery at the High Magnetic Field Frontier

Core capabilities of the HMF Beamline:

(1) Diffraction / Crystallography / Diffuse Scattering with High Energy X-rays
(2) Resonant Elastic X-ray Scattering (Polarization-analyzed scattering from magnetic moments)
(3) X-ray Absorption Spectroscopy (XANES, EXAFS)
(4) X-ray Magnetic Dichroism (Absorption spectroscopy variation with linear/circular polarization)
(5) High-resolution backscattering (Ultra-precise lattice constant measurements)







IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

HTS and Muon Colliders

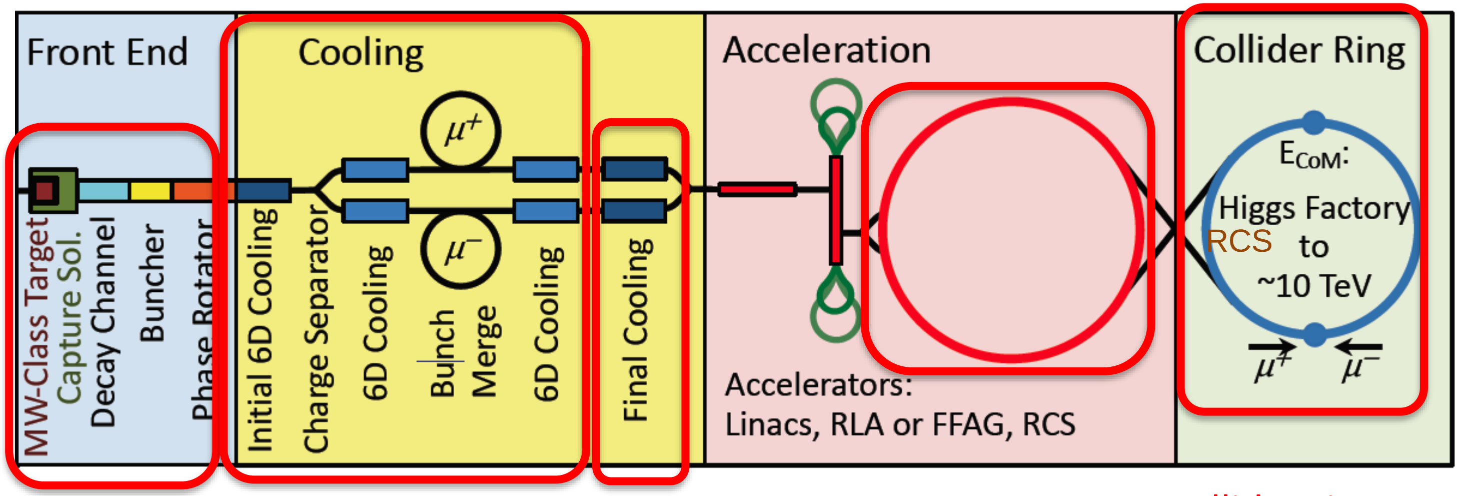
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

Muon Collider magnet “specs”

Target solenoids
Field: ~20T (15T) … 2T
Bore: 1200 mm
Length: 18 m
Radiation heat: ≈ 4.1 kW
Radiation dose: 80 MGy

6D Cooling solenoids
Field: 4 T … 19 T
Bore: 90 mm … 600 mm
Length: 1 km (x 2)
Radiation heat: TBD
Radiation dose: TBD

Accelerator magnets
Field: ±1.8 T (NC), < 10 T (SC)
Rate: 400 Hz (NC), SS (SC)
Bore: 100 mm(H) x 30 mm(V)
Length: 3 m … 5 m (x 1500)
Radiation heat: ≈ 3 W/m
Radiation dose: TBD

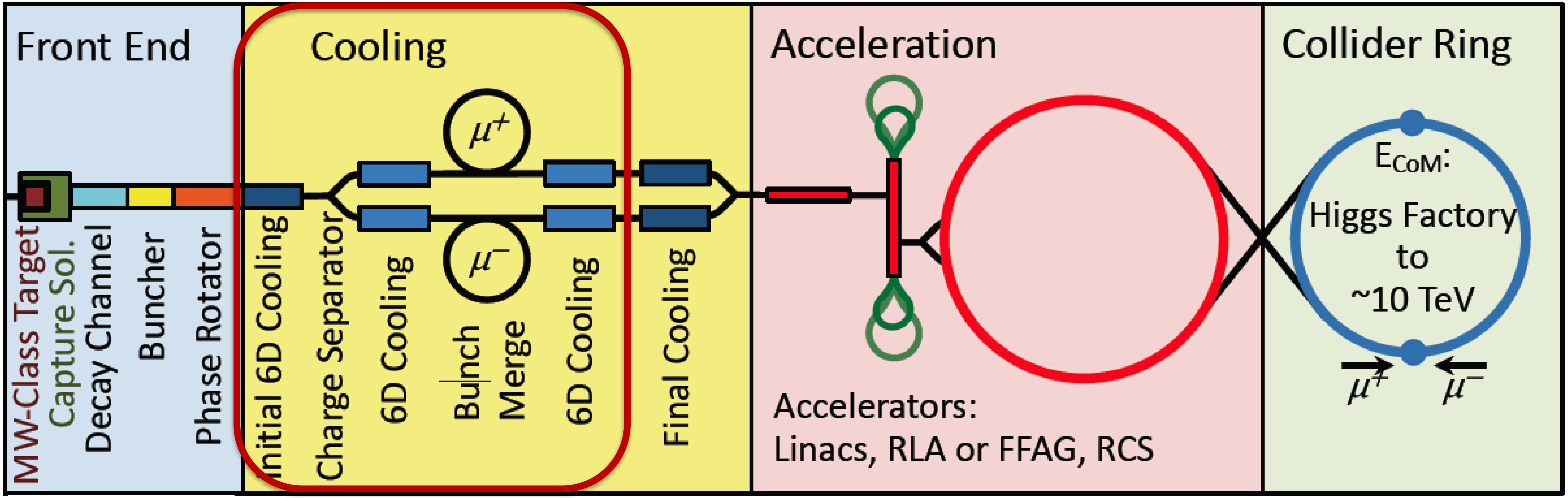


Final Cooling solenoids
Field: ≥30T (MAP), ≥40T (IMCC), ideally ≥50 T
Bore: 50 mm
Length: ≈ 500 mm (x 17)
Radiation heat: TBD
Radiation dose: TBD

Collider ring magnets
Field: 16 T peak (IR 20 T) – NOT a hard requirement! $\mathcal{L} \propto B_{dip}$
Bore: 150 mm
Length: 10 m … 15 m (x 700)
Radiation heat load: ≈ 5 W/m
Radiation dose: ≈ 20…40 MGy

6D Cooling

6D Cooling solenoids
Field: 4 T … 19 T
Bore: 90 mm … 600 mm
Length: 1 km (x 2)
Radiation heat: TBD
Radiation dose: TBD



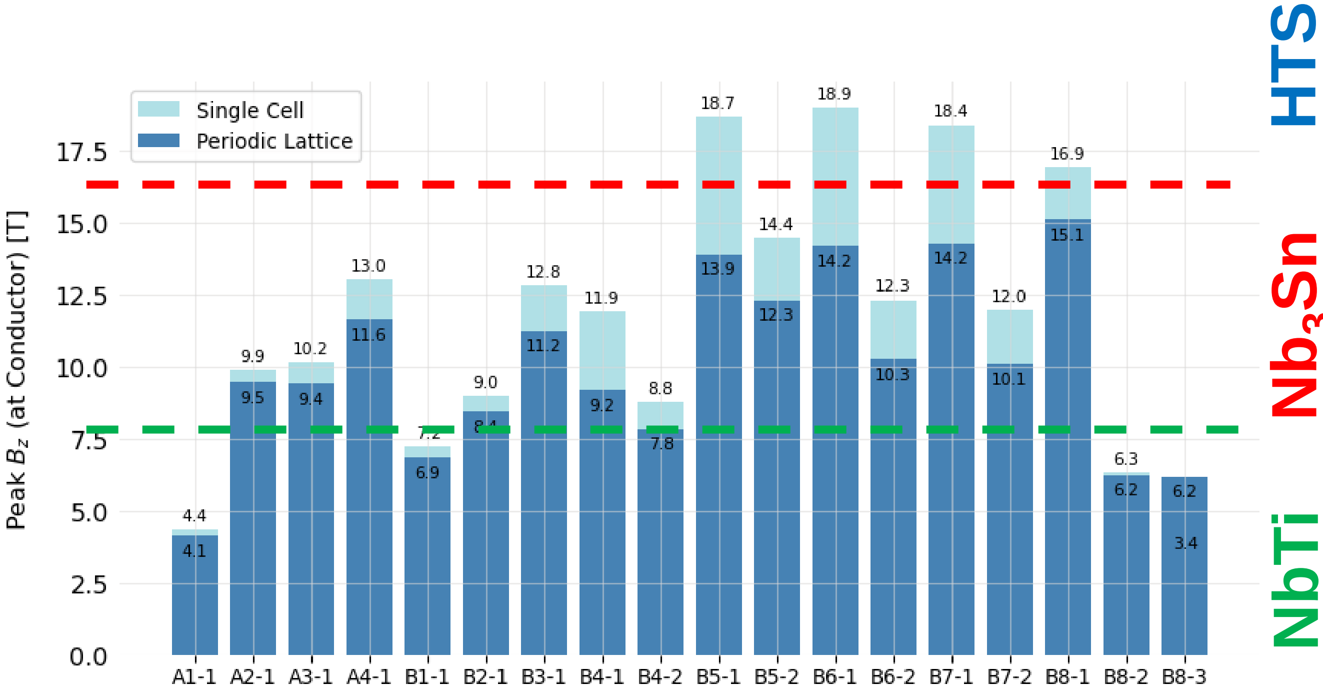
Cooling Channel

Full list based on original US MAP design (field on axis)

- 12 unique stages:
  - 4 cooling stages *before* bunch recombination (A1-A4)
  - 8 cooling stages *after* bunch recombination (B1-B8)
- *Each stage has a repeating series of a cell type*
- High field, very compact solenoids
- Each cell has symmetric solenoids of opposite polarity

Some stats:

- Fields on axis: 2 to 14 T
- Cell Lengths: 0.8 to 2.7 m
- Total length of all Stages: ~ **1 km**
- Total number of solenoids: 2432



By S. Fabbri and J. Pavan

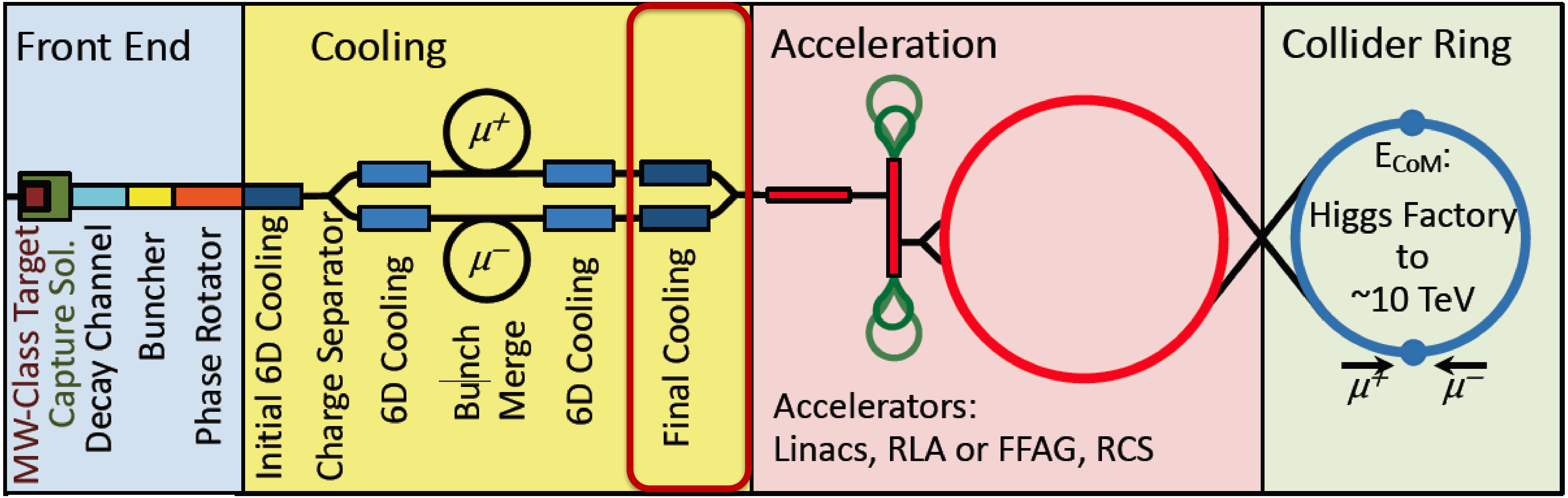
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

Technologies 6D cooling solenoids

Technology	Pro's	Con's
LTS	Known technology (TRL 9)	Operating temperature
HTS ReBCCO Insulated	More compact than LTS/HTS Allows for operation at higher temperature Batch above 100 m demonstrated	R&D at low readiness (TRL 4/5) Quench detection protection Production of km batches to be demostrated
HTS ReBCCO Non-insulated	Most compact magnet winding Synergies with other fields of science and societal applications Batch above 100 m demonstrated Can profit from development by others (e.g. NHMFL)	R&D at low readiness (TRL 3/4/5) Ramping time and field stability need to be demonstrated Quench detection and protection Production of km batches to be demostrated
HTS BiSSCO/IBS	Round wire demonstrated for BiSSCO	R&D at low readiness (TRL 3/4) for IBS Production lengths (?)

Fermilab

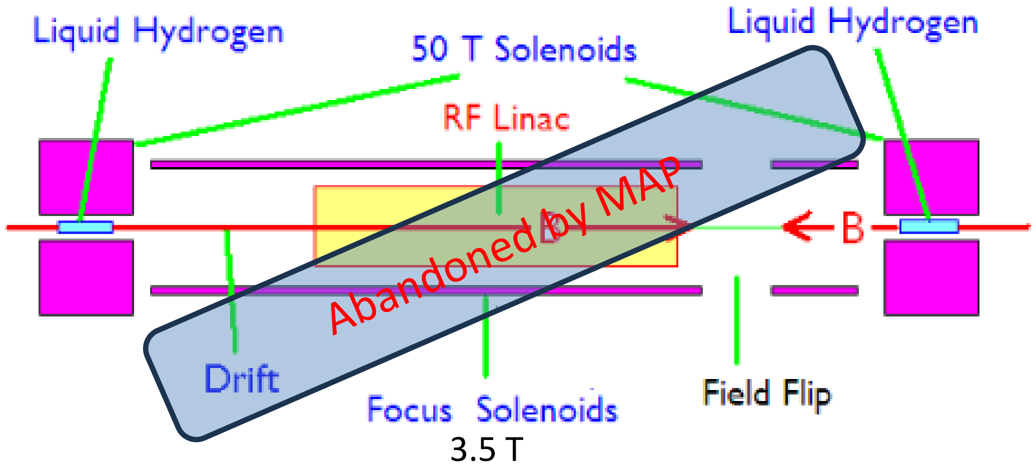
Relevance to Muon colliders Final Cooling Channel



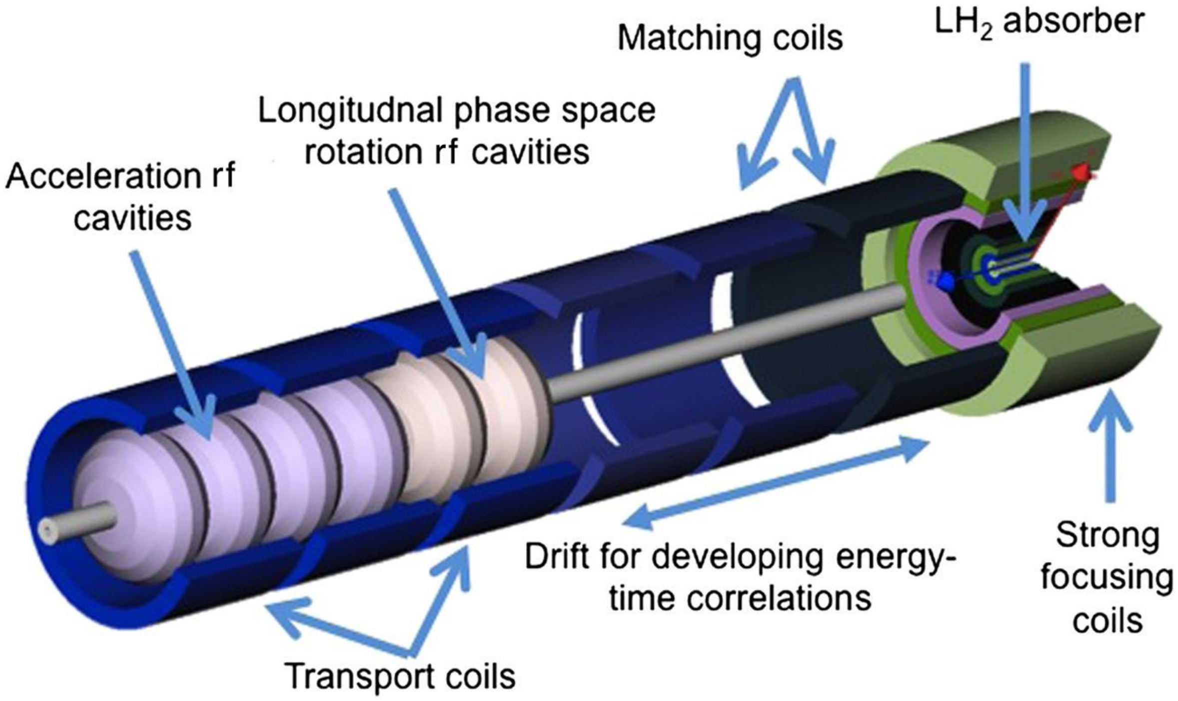
Final Cooling solenoids
Field: ≥30T (MAP), ≥40T (IMCC), ideally ≥50 T
Bore: 50 mm
Length: ≈ 500 mm (x 17)
Radiation heat: TBD
Radiation dose: TBD

Ionizing Cooling Cell　　Final cooling Cell

- 16 Cells (MAP)
  - Set of eight superconducting coaxial coils
  - Peak field of **30T,** 50 mm diameter
  - Sayed et al. Phys. Rev. ST Accel. Beams **18**, 091001
- 14 Cells (CERN-IMCC)
  - B > 40T, 50 mm diameter



R. Palmer, BNL

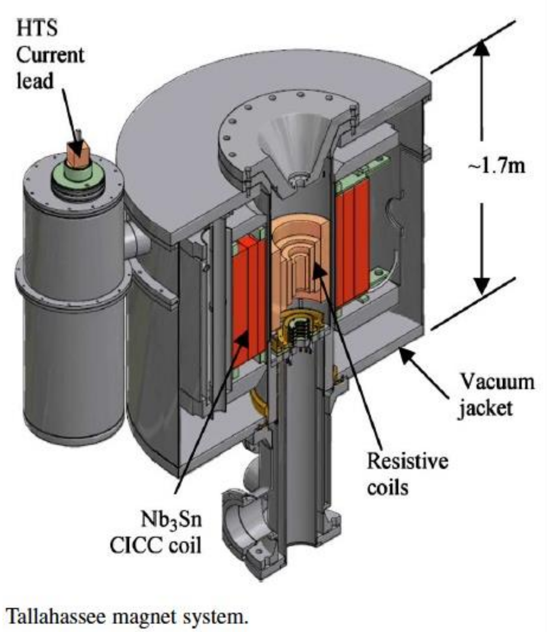


MAP 30T Design

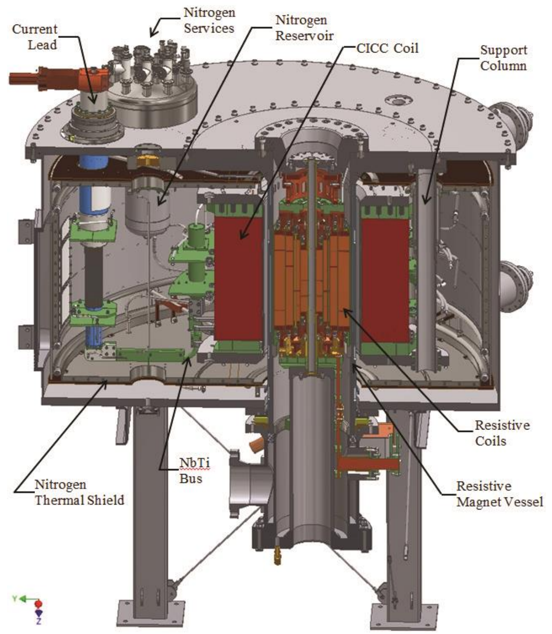
MagLab has developed high field solenoids

https://nationalmaglab.org/user-facilities/dc-field/magnets-instruments/

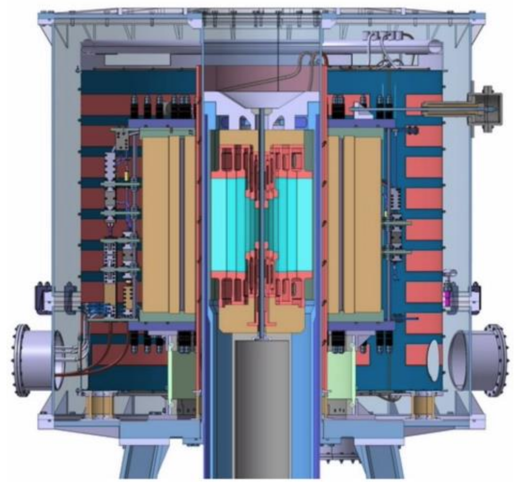
http://english.hmfl.cas.cn/uf/ms/202202/t20220224_301451.html



Cross section of 45 T, **32 mm** **NHFML** user facility solenoid
Hybrid Magnet 33.5 T from resistive insert, 11.5 T by superconducting outsert
30 MW power comsumption



Cross section of **36 T**, **48 mm** **NHFML** user facility (NMR) solenoid
Hybrid Magnet 23 T from resistive insert, 13 T by superconducting Nb_3Sn CICC outsert
14 MW power comsumption

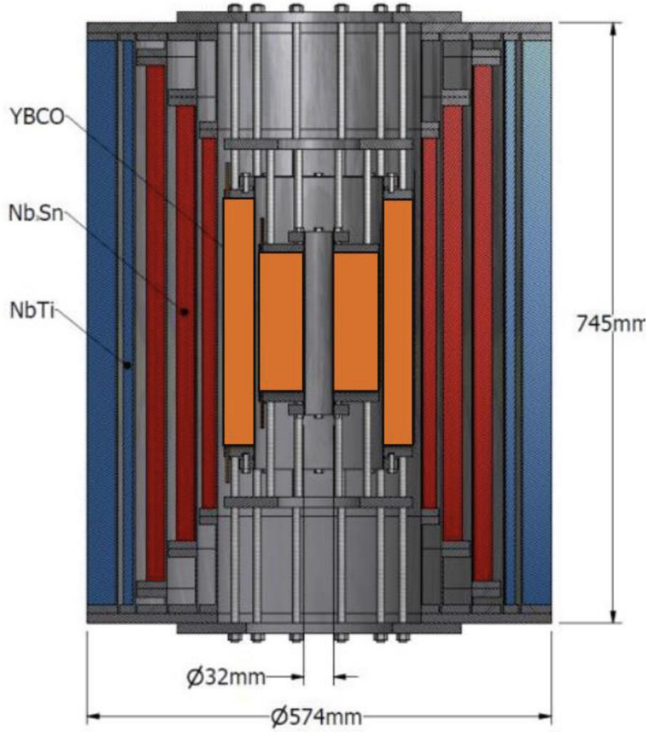


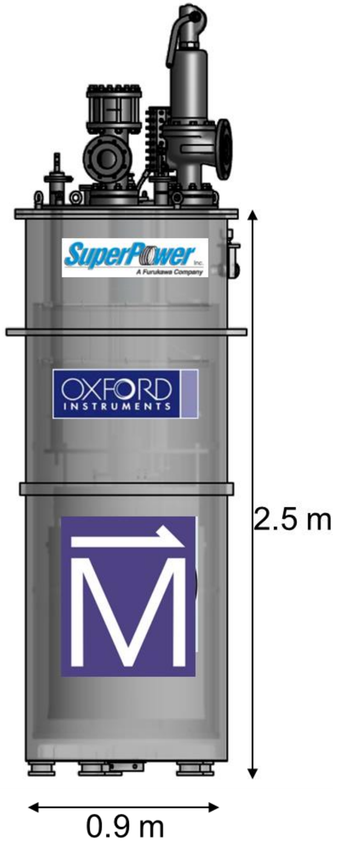
Cross section of **40*/37 T**, **32/50 mm** **CHMFL** user facility solenoid
Hybrid Magnet 29/26 T from resistive insert, 11 T by superconducting Nb_3Sn CICC outsert
20 MW power comsumption

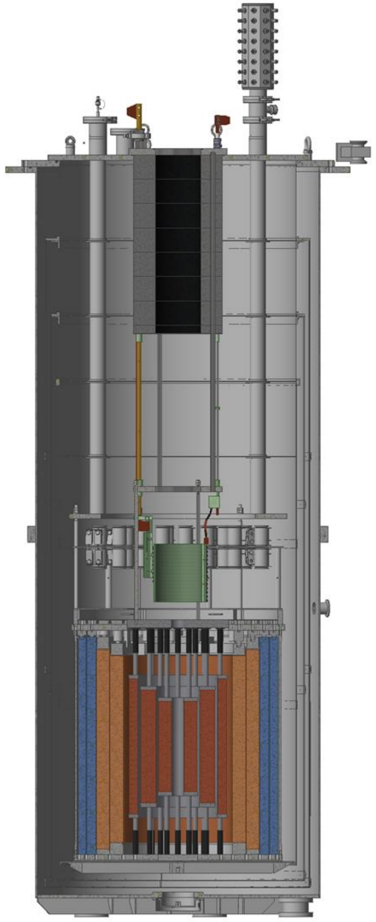
Getting closer to muon collider

Cross section of **32 T** (15 T LTS, 17 T two ReBCO double pancake coils), **32 mm** user facility solenoid

https://nationalmaglab.org/user-facilities/dc-field/magnets-instruments/





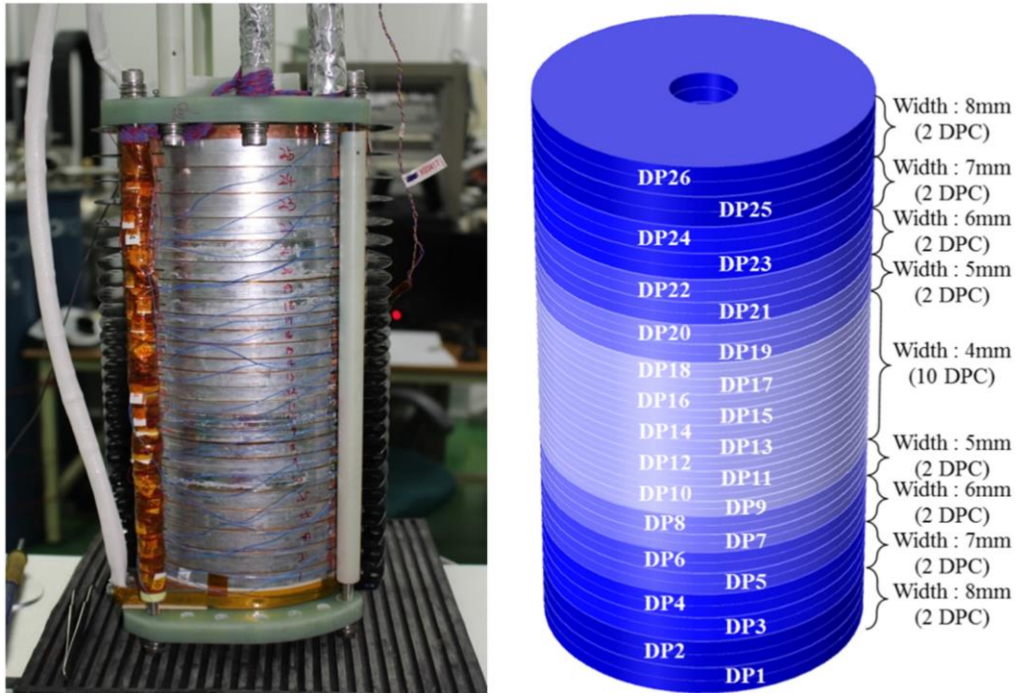


40 T magnet cross section

CERN approach

Sunam NI one-body ReBCO magnet
26.4 T in 35 mm, J central pancake 404 A mm^{-2}
(26.4 T HTS multi-width)
overall diameter and height: 172 and 327 mm

- Single coil, high J_e
  - 40T, 50 mm bore
- Need higher field – but higher tensile radial stress
- Apply precompression to all-HTS NI/MI single coil.
- High potential for future particle accelerators and other societal applications
- Substantial progress on design
- Challenges
  - High stresses
  - Magnet protection – transients to control
  - Charging time



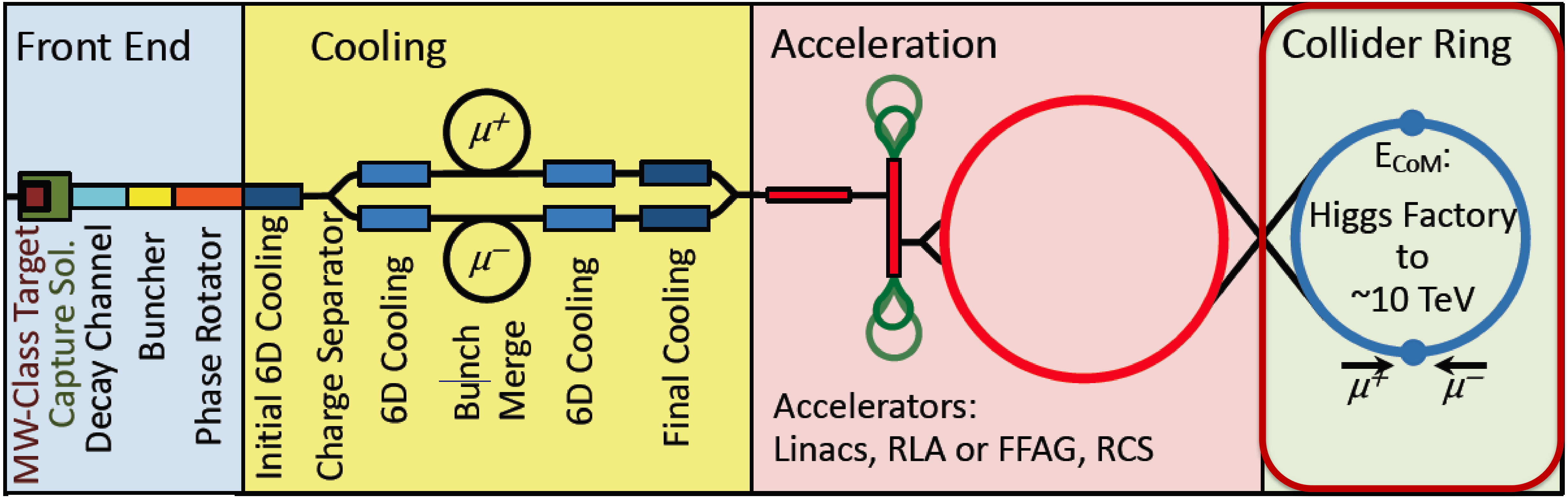
S. Yoon et al. Supercond. Sci. Technol. 29 (2016) 04LT04

B. Bordini, CERN

Collider Magnets

10 TeV IMCC Targets

Collider ring magnets
Field: 16 T peak (IR 20 T)
Bore: 150 mm
Length: 10 m … 15 m (x 700)
Radiation heat load: ≈ 5 W/m
Radiation dose: ≈ 20…40 MGy



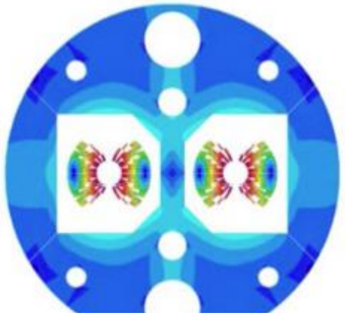
IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

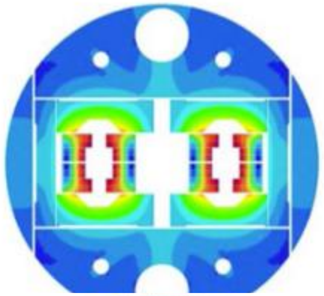
Material Options

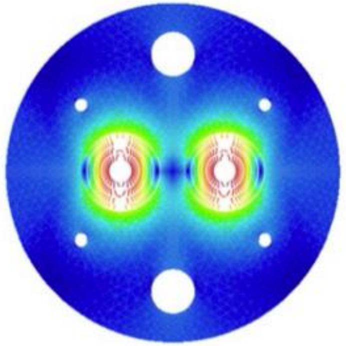
Technology	Pro's	Con's
LTS (Nb-Ti)	• Known and well developed technology (TRL 8)	• Probably do not meet all magnet requirements
LTS (Nb_3Sn)	• Known technology, reaching demonstration level in accelerators (TRL 6/7)	• Probably do not meet all magnet requirements • Brittle/stress limited
Hybrid (LTS Nb_3Sn) + (HTS)	• Lower cost • Exploit potential of both materials	• Low readiness level for HTS insert (TRL 3/4) • LTS/HTS joints and integration to be developed • Temperature limited by LTS
All-SC (HTS): Insulated Controlled Insulated Non Insulated	• Most compact solution • Allows operation at high temperature • Profit from on-going R&D activities on insulation/no-insulation windings	• R&D at low readiness (TRL 3/4) • Quench protection to be demonstrated • Field delay and field stability in case of NI winding

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

Design Options (1/2)







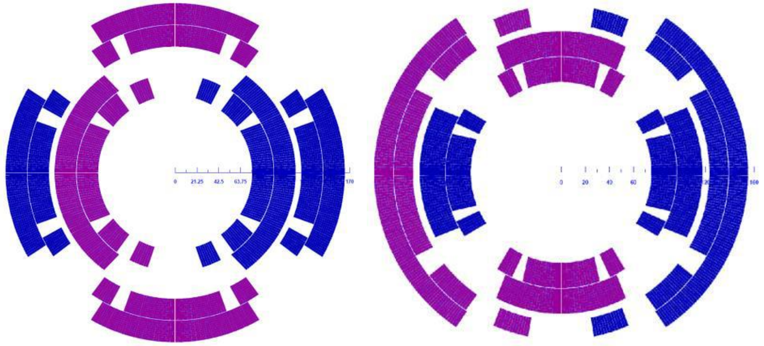
CCT

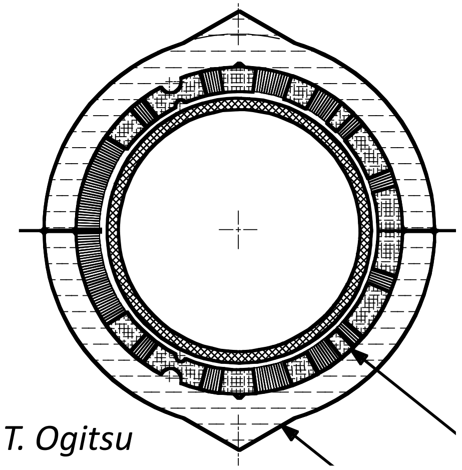
Technology	Pro's	Con's
Cos-theta Design	• Well known design • Wound around a cylindrical mandrel, end shape already suitable for beam tube insertion	• Mechanical structure can be complex • Not most easy winding geometry for HTS tapes
Block Coil Design	• Known design principles • Mechanical structure simplify stress management • Easier geometry for HTS-tapes	• Difficult stress management on coil ends • Higher ratio conductor length/produced field
Canted Cos-theta Design	• Intrinsic stress management • Low number of parts and tools • Easy winding procedure	• Requires more cable than the other layouts • Quench protection more difficult • R&D needed

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.

Design Options (2/2) Combined function

A. Zlobin





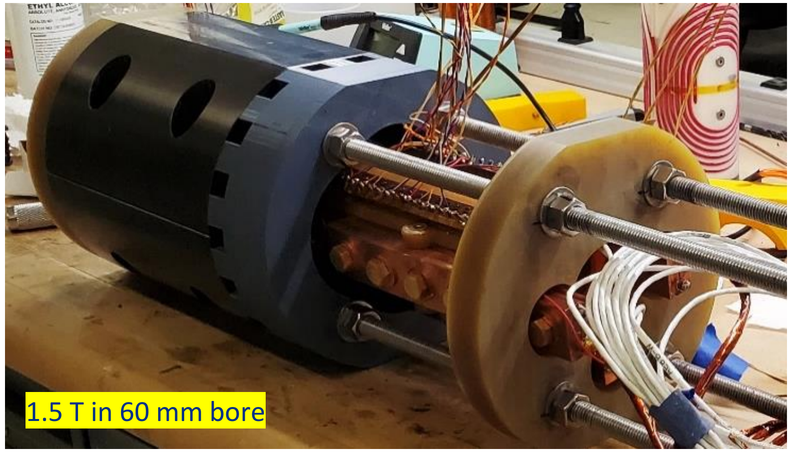
T. Ogitsu

Technology	Pro's	Con's
NESTED Configuration	• Separate Powering Dipole/Quadrupole • Inherit experience on Nb_3Sn magnets for HiLumi and LARP-US development program	• High Stress on Internal Coil • Alignment • Higher Costs
Asymmetric Coil Design	• Single type of coil • Optimized margin and field quality	• Fixed Dipole/Quadrupole ratio • Stress on the supporting structure is not balanced

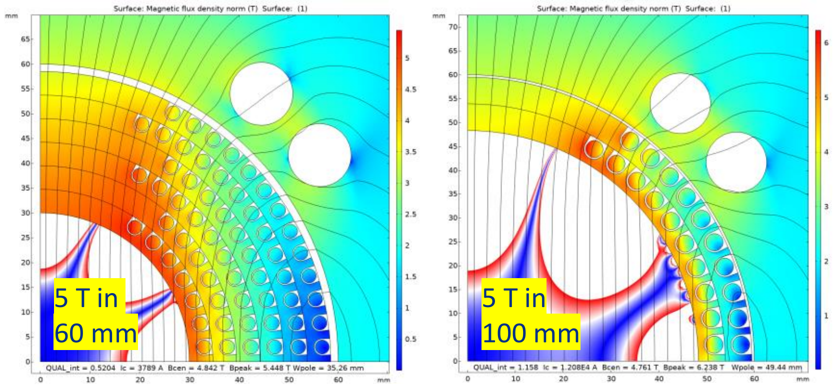
Fields for 3 TeV are high, but 10 TeV very high!

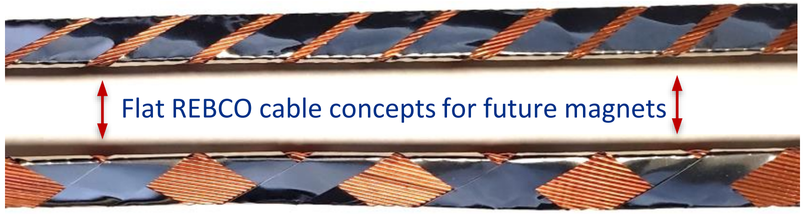
Important negotiation point with machine designers

HTS (REBCO) magnet and cable development



REBCO magnets with round cables





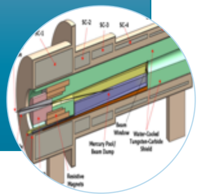
- REBCO accelerator magnet development
  - State-of-the-art STAR and CORC round wires
  - First REBCO magnet tested in LHe this year
    - Innovative coil structure 3D-printed from ULTEM
    - Reached 1.5 T in a 60-mm bore
  - Two REBCO magnets to be fabricated and tested in 2025-26
    - Target 5 T field in 60-100 mm bores
    - Standalone and inserts into Nb_3Sn coils
- Alternative REBCO cable designs for accelerators
  - SBIR proposal for flexible flat cable development
  - Fully-transposed tape-based cables
- Fusion cable studies
  - Several proposals for collaboration with PPPL
  - Use our core capabilities – electromechanical characterization of different conductors
    - Start from cable stack studies
    - Expand into small coil/magnet studies

Fermilab

Summary of the Muon Collider Magnet Pull

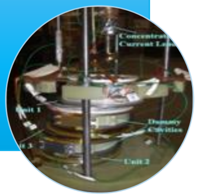
- Characteristics:
  - High field (15-20T)
  - Large bore (meter-scale)
  - Intense radiation environment – NC or HTS insert coil

Capture Solenoid for Simultaneous mu+ & mu- Beams



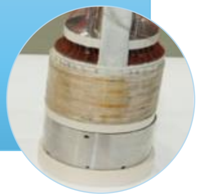
- Characteristics:
  - Solenoid-based cooling channel (LH_2/LiH absorbers)
  - RF cavities integral to focusing channel
  - Fields ranging from LTS to HTS conductor regime

Muon Ionization 6-Dimensional Cooling Channel



- Characteristics:
  - Emittance exchange channel for TeV-scale colliders – trade increased longitudinal beam emittance for smaller transverse emittance
  - Goal: 40-60 T HTS solenoids with d ~ 50mm

Muon Ionization Final Cooling Channel

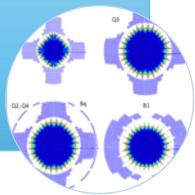


- Characteristics:
  - Present baseline based on the use of Rapid Cycling Synchrotrons
  - Requires magnets capable of ~400Hz operation with B>1.5T
  - Novel magnets, suitable modeling, efficient power system

Acceleration to the TeV Energy Scale for Muon Colliders

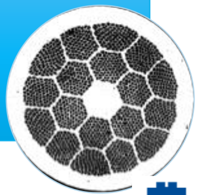
- Characteristics:
  - Decaying muon beams mean that luminosity is inversely proportional to circumference
  - 10T dipole ➪ 15-20T dipoles improves luminosity
  - Radiation environment
  - Challenging IR magnets

Muon Collider Magnet Needs



- Characteristics:
  - A MC (w/decaying beams) obtains the greatest performance enhancement of any HEP collider from HTS magnet technology
  - High quality HTS cables and magnets must be a priority

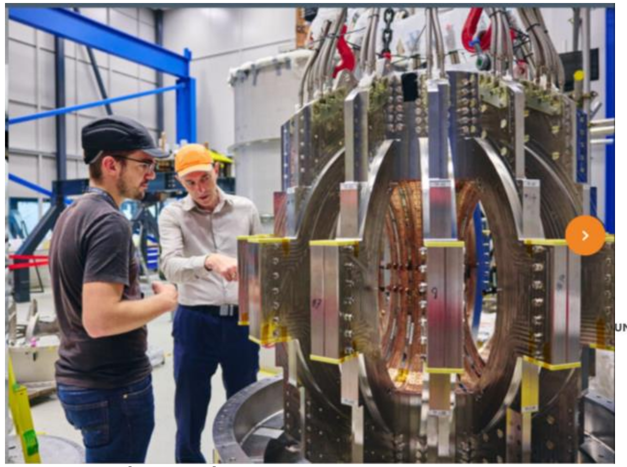
HTS Magnet Development



Brookhaven National Laboratory

Fermilab

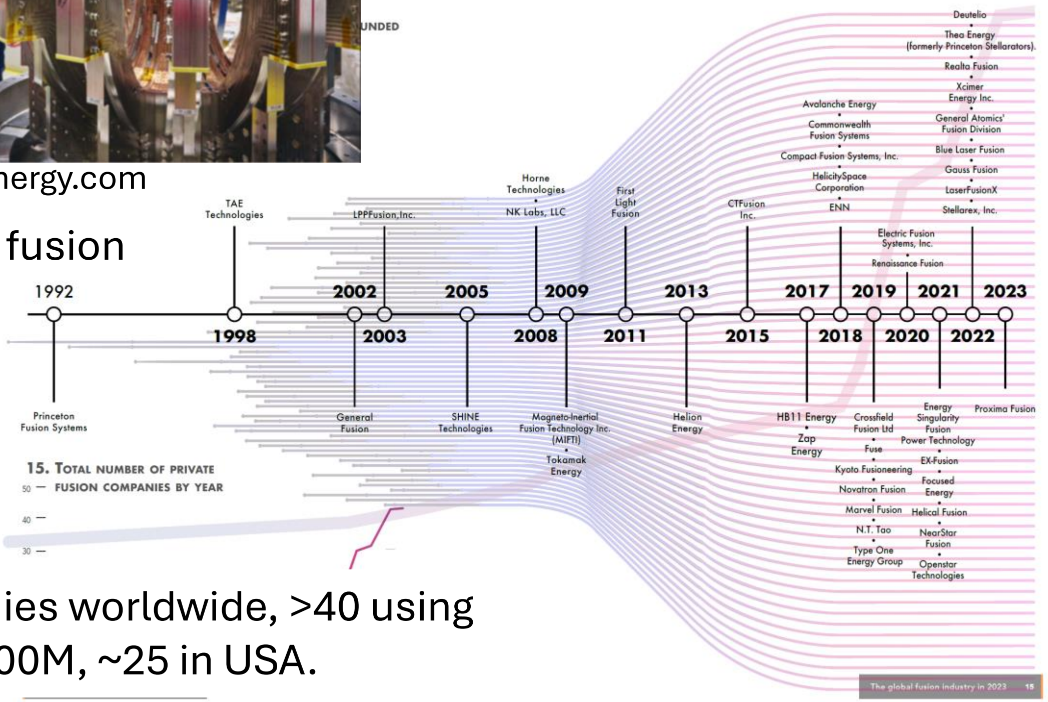
Disruptive Technologies – Fusion



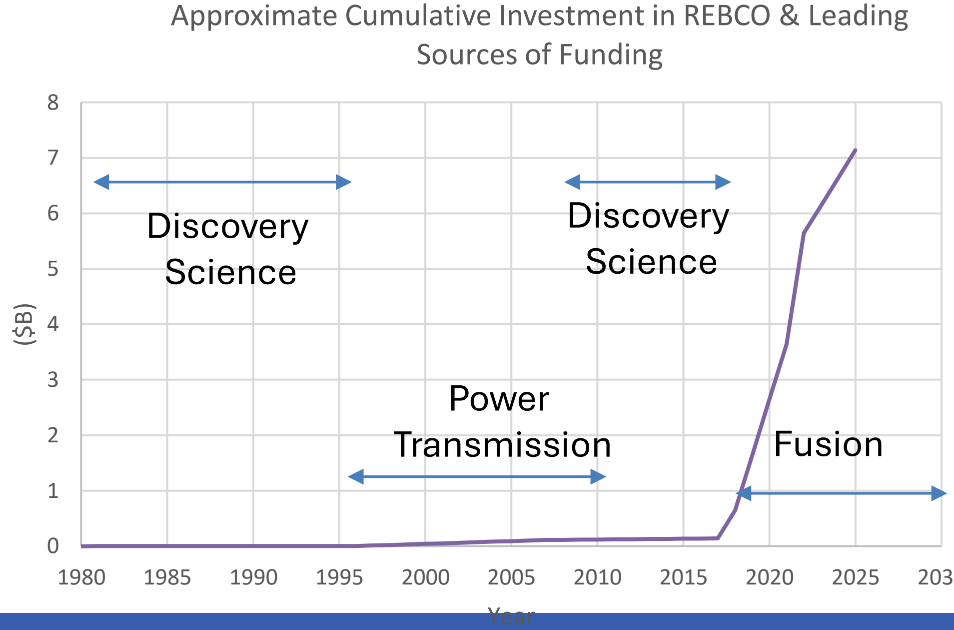
www.tokamakenergy.com

There are opportunities for R&D contracts with the commercial fusion sector!

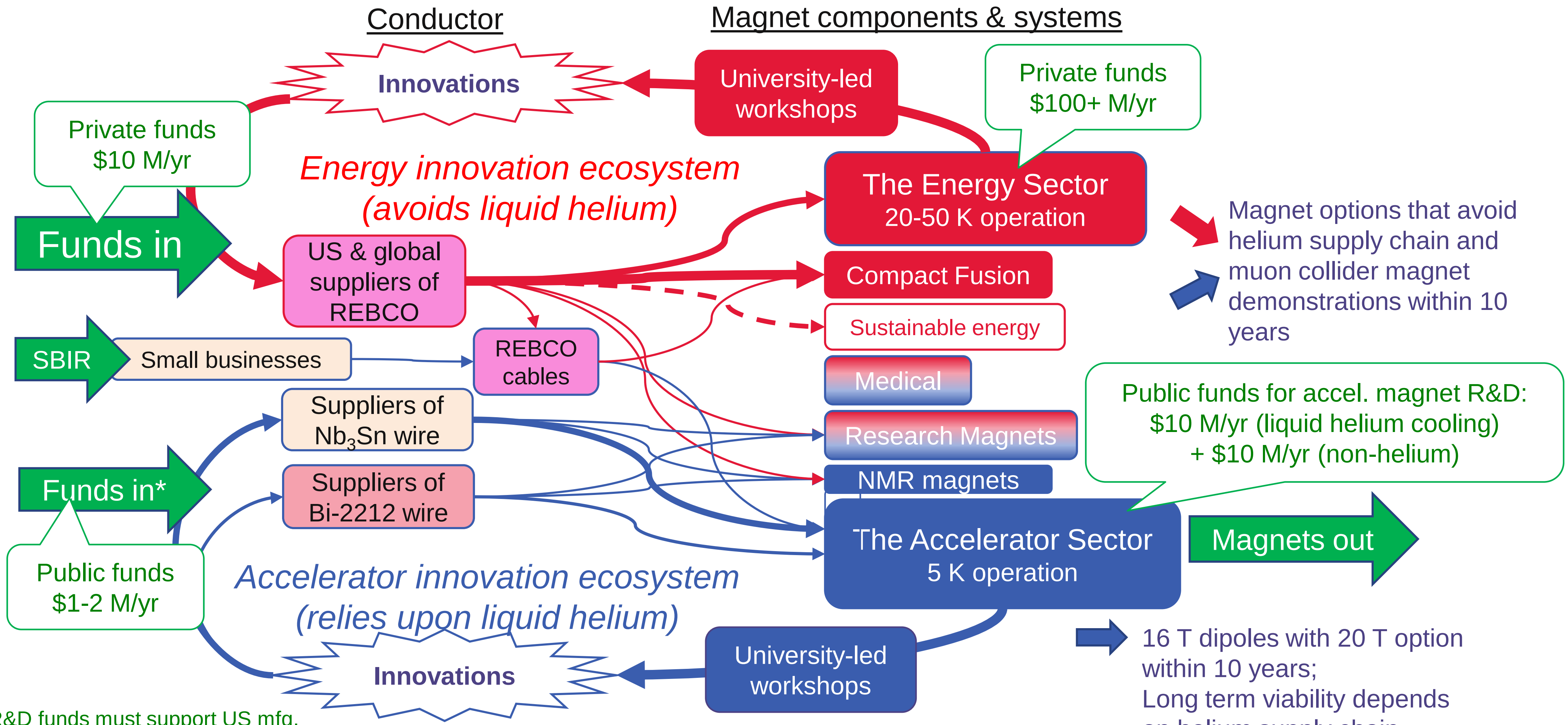
Timeline of when fusion companies were founded.



Today >45 companies worldwide, >40 using magnets, 8 w/ >$200M, ~25 in USA.



The different communities should synchronize innovation ecosystems



* R&D funds must support US mfg.
Procurements must obey Buy America

Summary

- MagLab 3.0 can play a vital role in the development of magnets across a broad range of discovery science areas and we are eager to partner
- HTS plays a critical role for future discovery science requiring high magnetic fields
- Partnerships are critical between multiple areas of discovery science requiring high field magnets
- Partnerships with industry are critical to the future of magnets in discovery science

IEEE-CSC, ESAS and CSSJ SUPERCONDUCTIVITY NEWS FORUM (global edition), Issue No. 59, May 2025. Presentation given at CCA 2025, March 11-13, 2025, Geneva, Switzerland.