Superconducting Magnet Division

Kathleen Amm
Division Head
ammk@bnl.gov

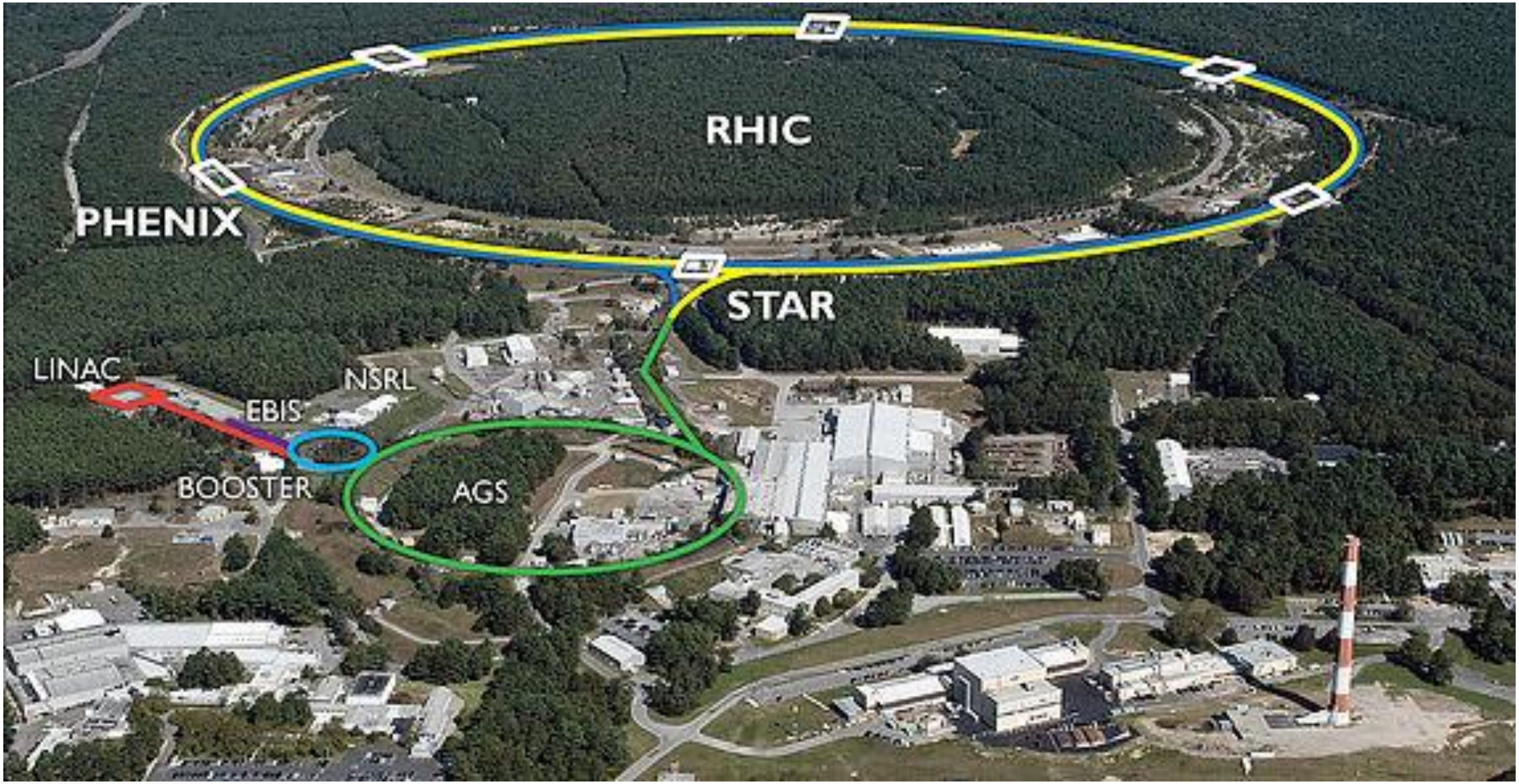
Outline

- Introduction
- Overview of accelerators
- SMD Mission and Vision
- History and current projects
- Future Opportunities
- Conclusion and Discussion

Kathleen Amm, New Head Superconducting Magnet Division

- Joined BNL October 2018 after 20 years at GE leading teams in superconducting magnets, MRI and generators
- Condensed matter physicist, superconductivity
- Primary areas of research- LTS and HTS superconductivity, Permanent magnets, MRI, superconducting generators

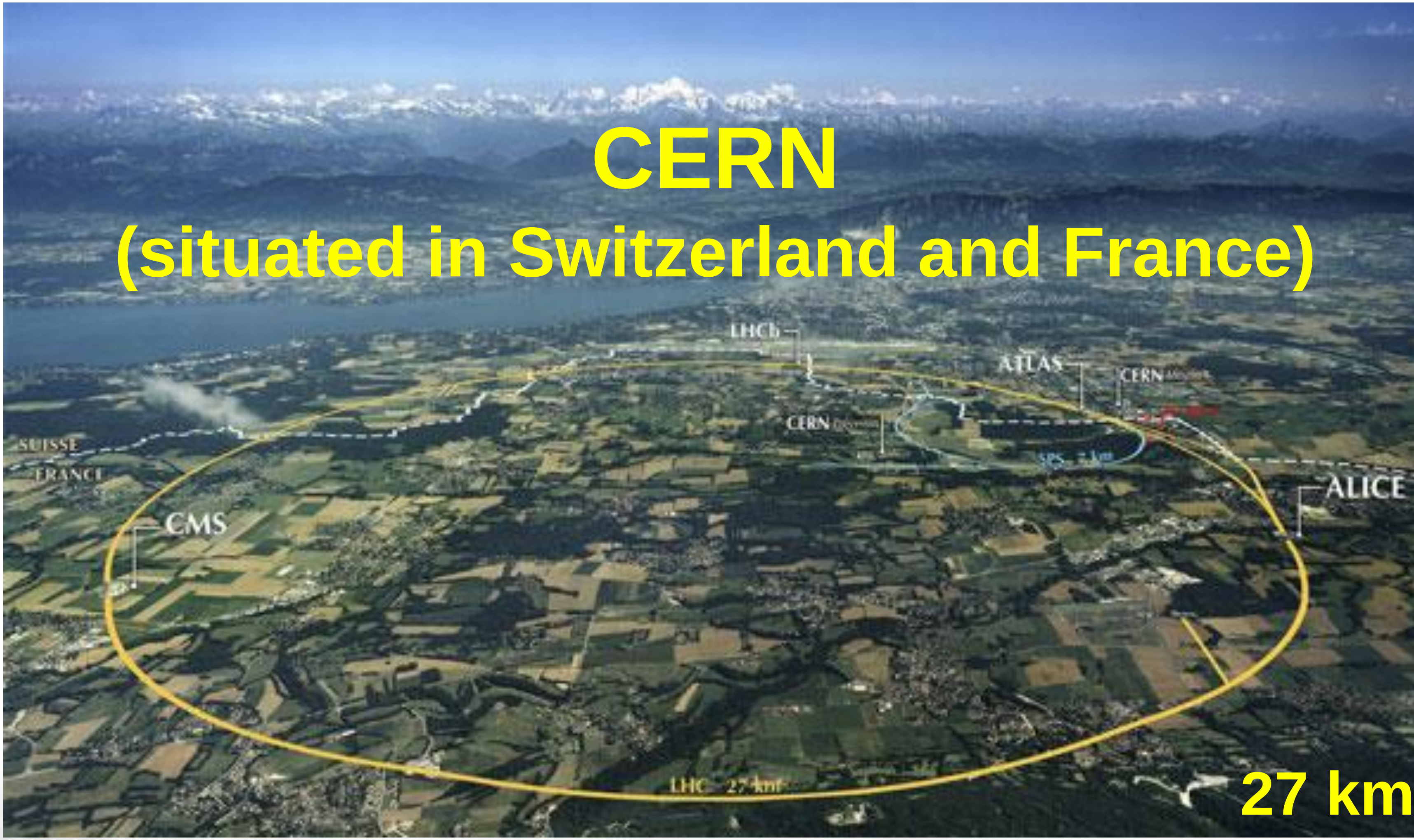
Relativistic Heavy Ion Collider



3.8 km circular tunnel

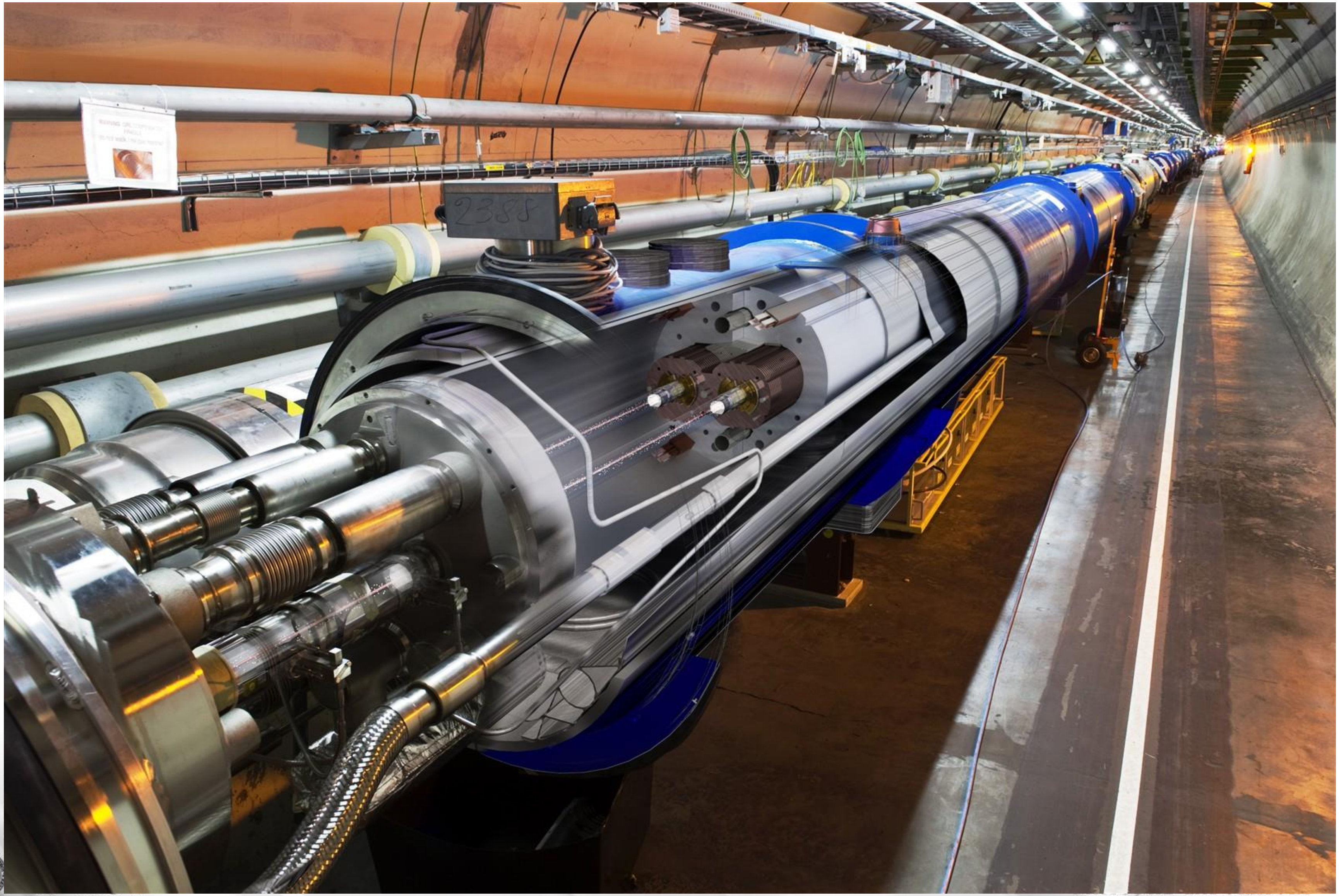
Superconducting Magnets inside the RHIC Tunnel

Large Hadron Collider (LHC)



Credits: Many pictures in this presentation are taken from web, a large number from CERN

Superconducting Magnets inside the LHC Tunnel



Major Accelerator Projects with Superconducting Magnets

Machine	Location	Energy	Circumference	Status
Tevatron	Fermilab, USA	900 GeV (p) X 900 GeV (p-)	6.3 km	Commisioned: 1983
HERA	DESY, Germany	820 GeV (p) X 30 GeV (e)	6.4 km	Commisioned: 1990
~~SSC~~	~~SSCL, USA~~	~~20 TeV (p) X 20 TeV (p)~~	~~87 km~~	~~Cancelled: 1993~~
~~UNK~~	~~IHEP, Russia~~	~~3 TeV~~	~~21 km~~	~~Suspended~~
RHIC	BNL, USA	100 GeV/amu X 100 GeV/amu (proton: 250GeV X 250 GeV)	3.8 km	Commisioned: 2000
LHC	CERN, Europe	7 TeV (p) X 7 TeV (p)	27 km	Commissioned: 2008

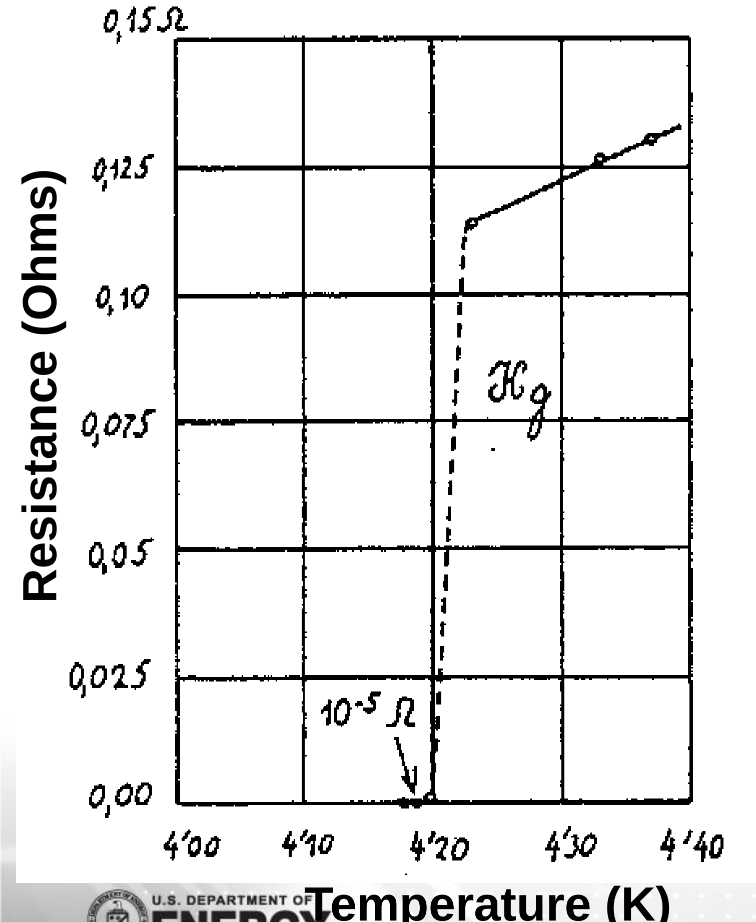
	Dipoles				Quadrupoles			
Machine	B(T)	Aper(mm)	Length(m)	Number	Grad(T/m)	Aper(mm)	Length(m)	Number
Tevatron	4	76.2	6.1	774	76	88.9	1.7	216
HERA	4.68	75	8.8	416	91.2	75	1.9	256
~~SSC~~	~~6.7~~	~~50~~	~~15~~	~~7944~~	~~194~~	~~40~~	~~5.7~~	~~1696~~
~~UNK~~	~~5~~	~~70~~	~~5.8~~	~~2168~~	~~70~~	~~70~~	~~3~~	~~322~~
RHIC	3.5	80	9.7	264	71	80	1.1	276
LHC	8.3	56	14.3	1232	223	56	3.1	386

Next generation colliders need 16-20 T magnets in 80-100 km tunnel

Low Temperature Superconductors (LTS) and High Temperature Superconductors (HTS)

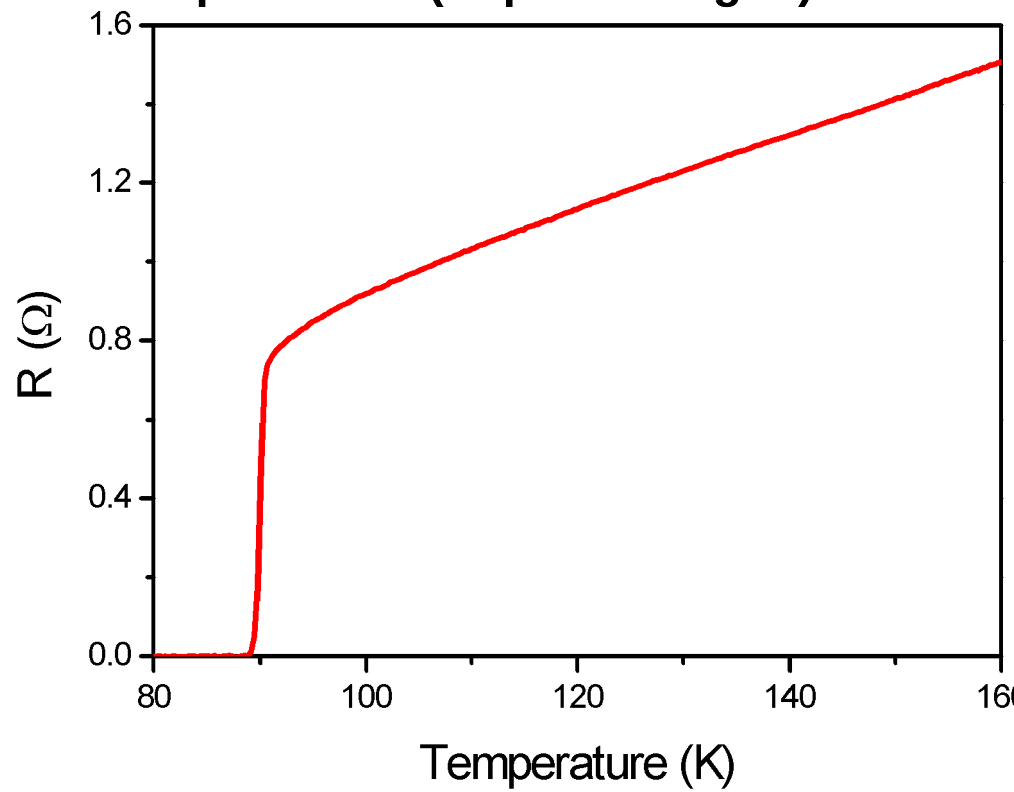
Low Temperature Superconductor Onnes (1911)

Resistance of Mercury falls suddenly below meas. accuracy at

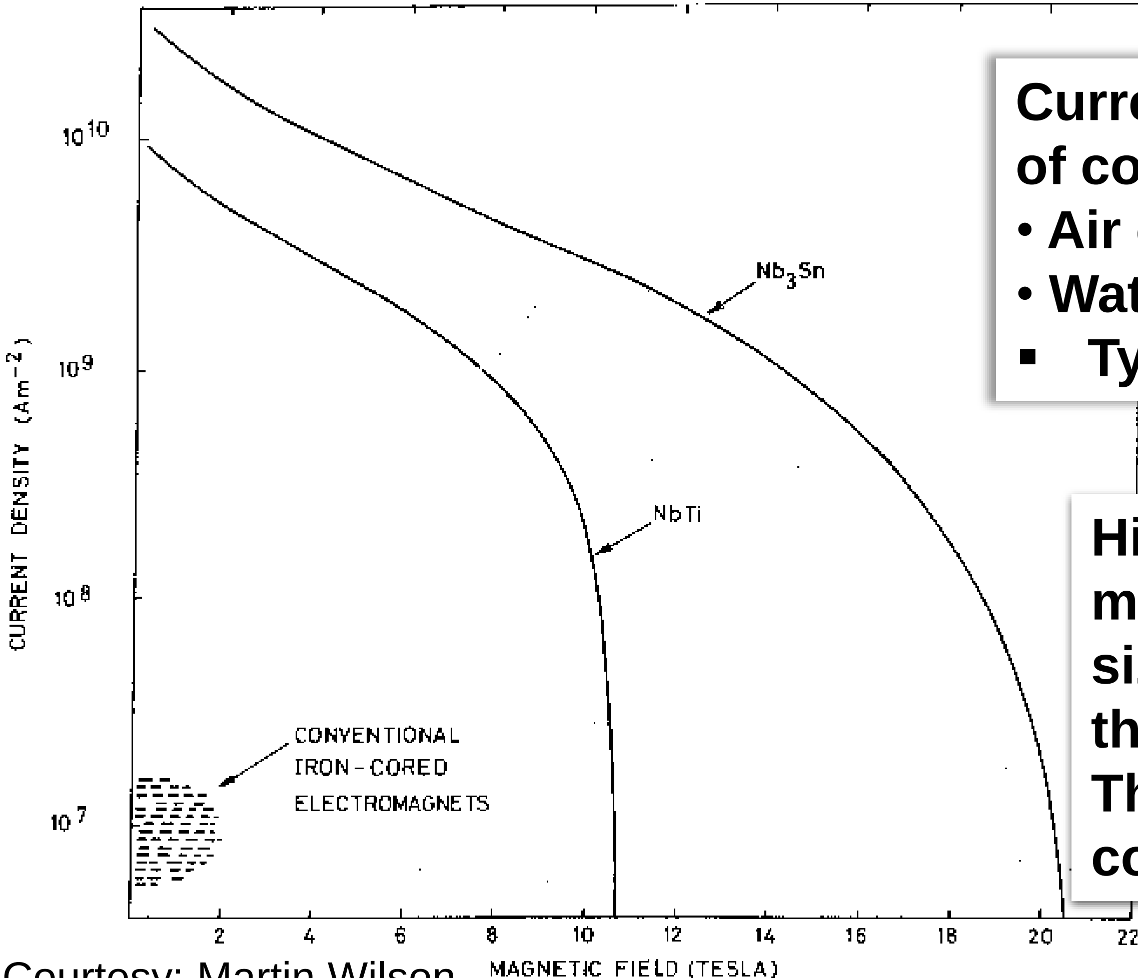


High Temperature Superconductors (1986)

They lose their resistance at NOT so low temperatures (Liquid Nitrogen)!



Why Use Superconducting Electro-magnets in Accelerators?



Courtesy: Martin Wilson

Current density in copper coils of conventional magnets:

- **Air cooled (max) ~ 1 A/mm^2**
- **Water cooled ~ 2-10 A/mm^2**
- **Typical fields: ~ 1-1.8 T**

High field superconducting magnets (3-8 T) reduce the size of the tunnel, as well as the cost of the operation. They make high energy colliders realistic.

Proposed field: 16-20 T, Current density >500 A/mm^2

Proposed High Energy Colliders

Present LHC at CERN

- CoM Energy: 14 TeV
- Tunnel Size: 27 km
- Dipole design field: 8.3 T
- Conductor used: NbTi

Proposals for Future

- CoM Energy: 80 - 100 TeV
- Tunnel Size: 60 - 100 km
- Dipole design field: 15-20 T
- Conductors: Nb_3Sn, HTS

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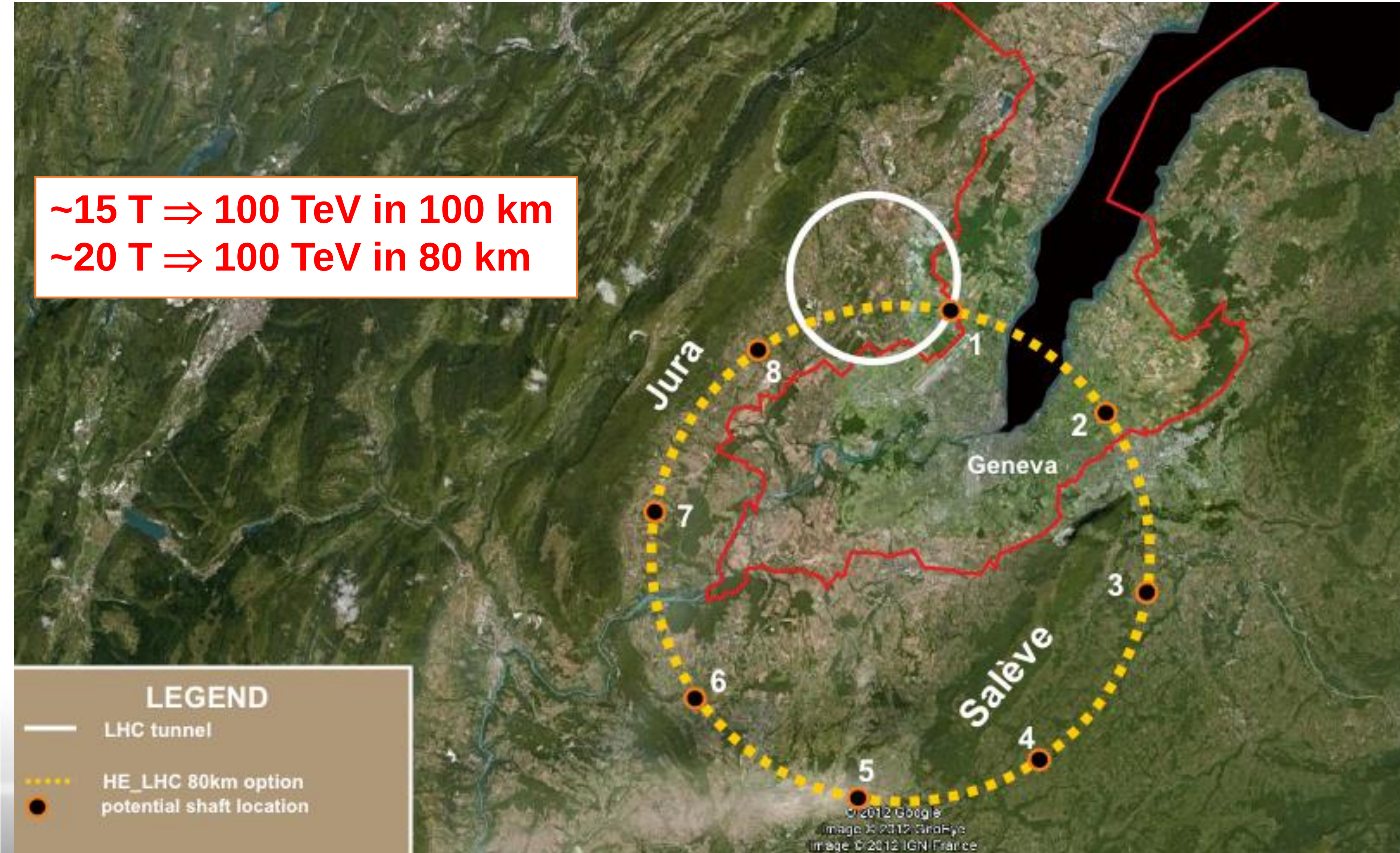
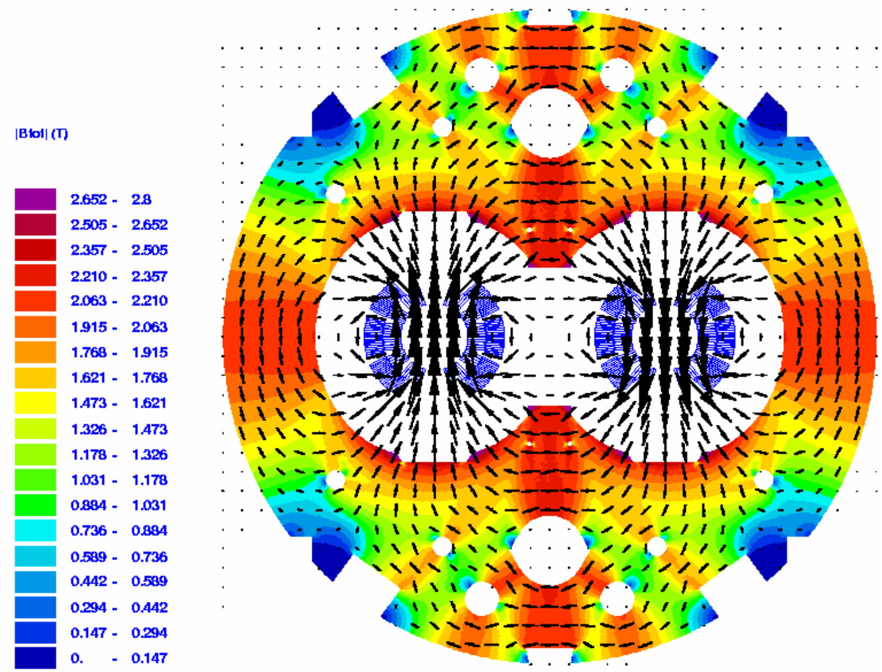
Future Circular Collider (FCC)



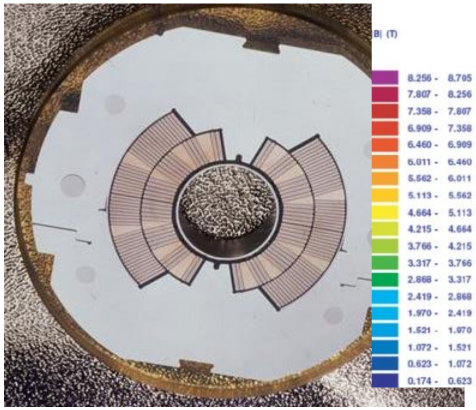
Mechanical and Magnetic Structure of LHC Dipole

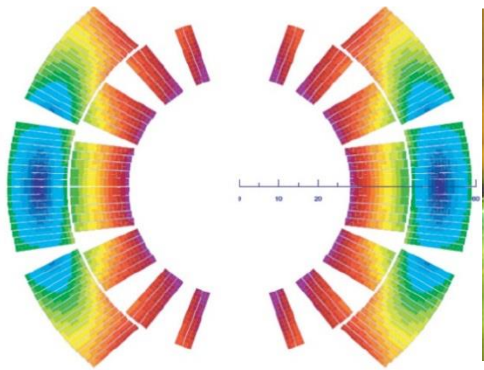


- **Field = 8.3 T**
- **Current = 11.8 kA**
- **Length = 14.3 m**
- **Weight = ~35 tonnes**
- **Number of magnets = 1232**

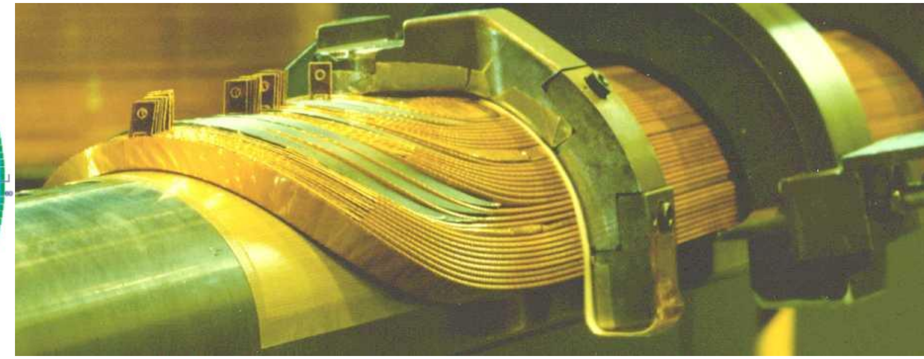
- **2-in-1 design (2 side by side coils in 1 yoke)**
- **Operating temperature: 1.8 K**
- **Field uniformity: a few parts in 10^4**
- **Stainless collars to hold large forces**
- **Forces on coil: 400 tonnes**
- **Stored energy in ring: 11 GJ**

Challenges with Present Magnet Designs and Technology

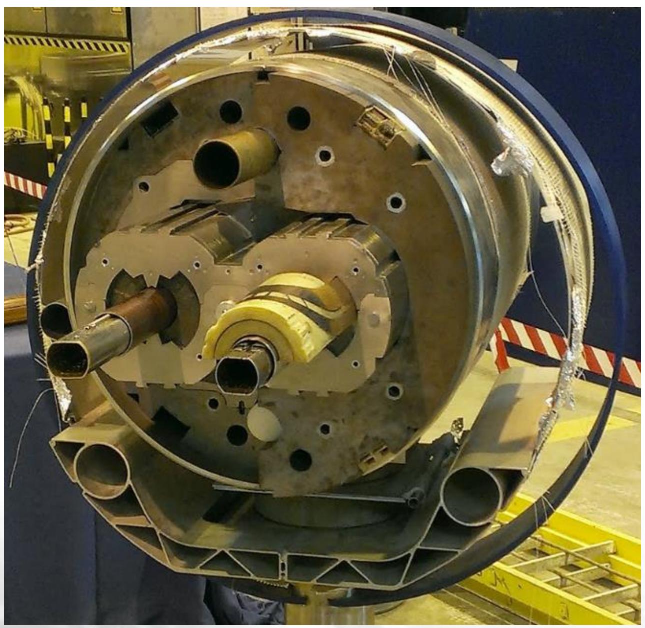




Coil cross-section



Coil end



- Cosine theta coil geometry with complex ends
- NbTi superconductor is practical up to 8-9 Tesla
- High field dipoles create large Lorentz forces
- Design and technology is in use for many decades - performance and cost unlikely to change much
- **Future colliders need new materials, new designs and perhaps new manufacturing techniques**

A major challenge for the next generation

SMD overview

SMD Vision

To be a world class superconducting and electromagnetics team creating the future of superconducting magnet technology

- Leadership in superconducting magnet technology, magnet development, manufacturing and testing
- With application to accelerator, science, fusion and industrial applications

SMD Mission

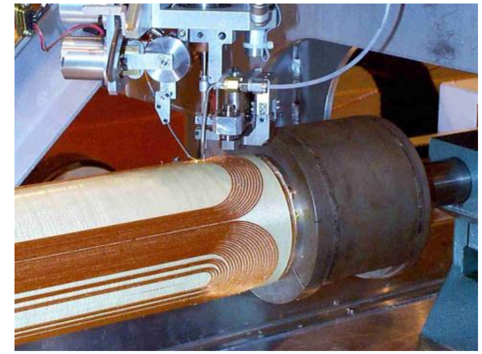
Utilize world class facilities to

- Advance the science and technology of superconducting magnets
- Apply these technologies to support accelerators, fundamental science discoveries, energy and other industrial applications requiring high magnetic fields
- Ensure a strong national talent pool for superconducting magnet development in the US

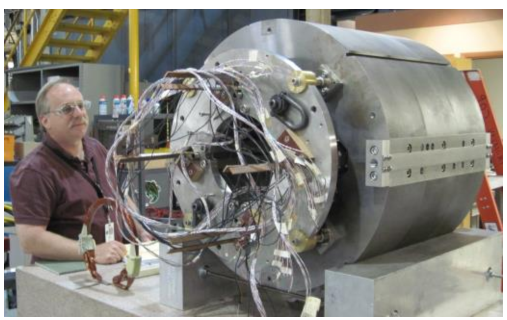
Superconducting Magnet Division – a Rich History

Relativistic Heavy Ion Collider – strong history of industrialization at Broohaven

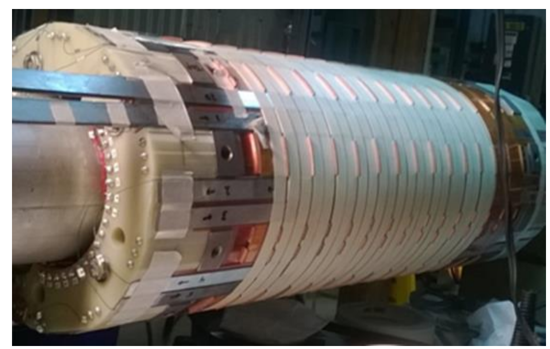
Magnets for Large Hadron Collider – Geneva, Switzerland



Hadron Electron Ring Accelerator magnet – Hamburg, Germany



High temperature superconducting magnet for Facility for Rare Isotope Beams, Michigan State



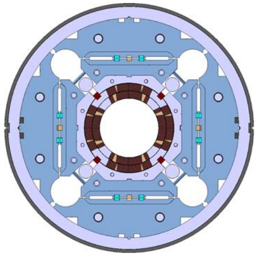
High temperature superconducting magnetic energy storage device

https://www.bnl.gov/magnets/projects.php

Superconducting Magnet Division – a Bright future

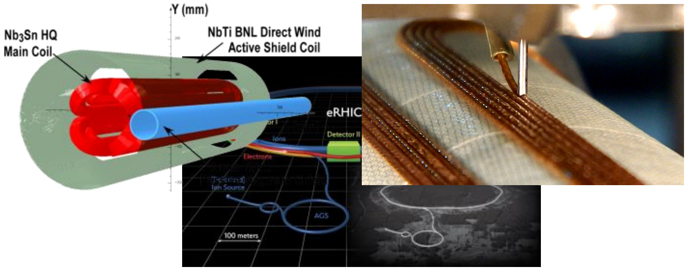
Team – 33 scientists, engineers, technicians, support staff

Capabilities – Magnet EM and Mechanical design, magnet testing, cryogenics

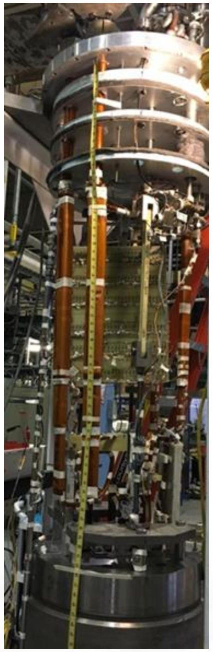


Facilities – Coil winding including automated, cold mass assembly, multiple magnet test facilities, cryoplant

Current Projects and thrusts-



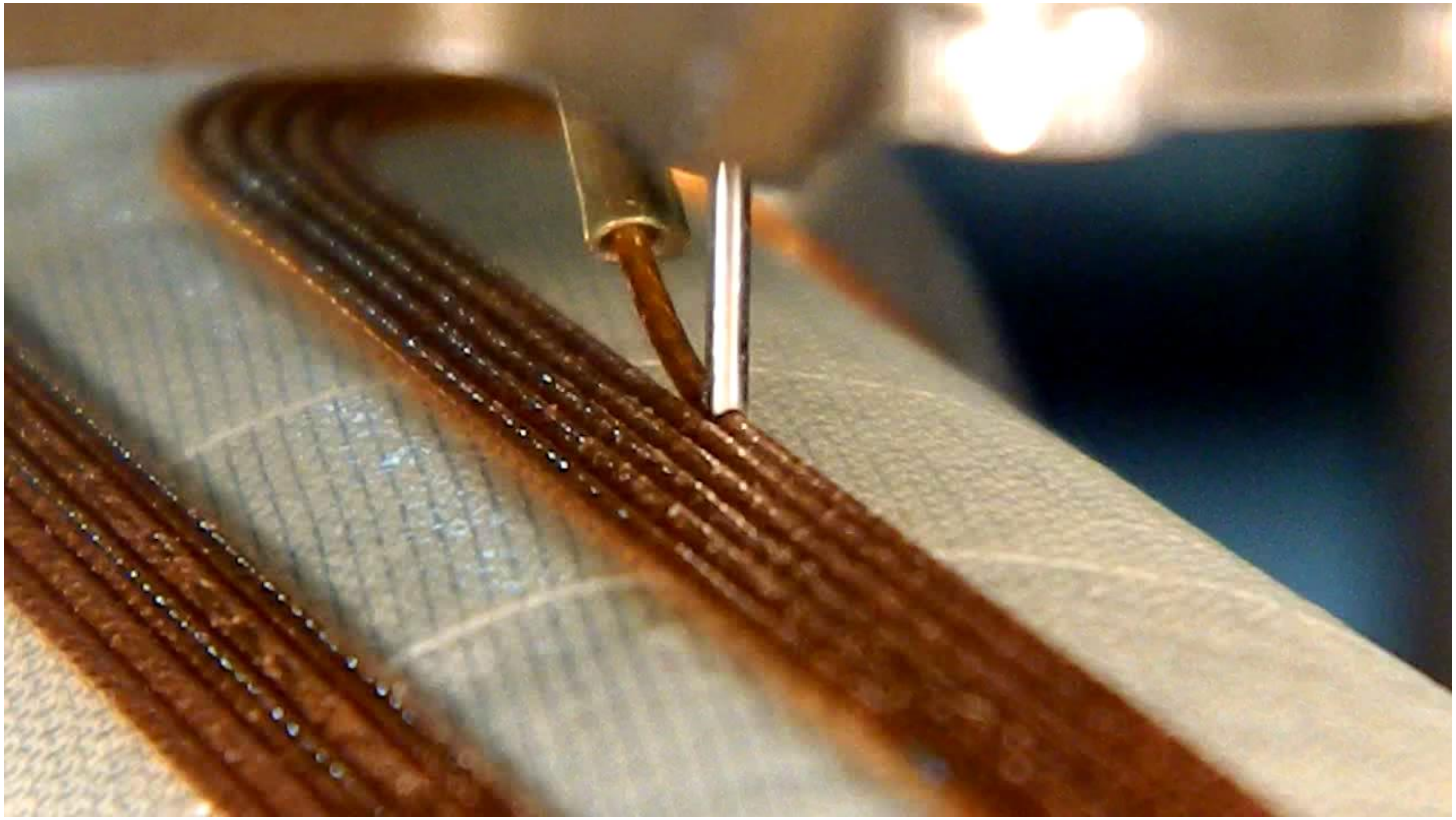
eRHIC design



Magnet Development Program

Magnets for the Large Hadron Collider High Luminosity upgrade

Direct wind machine

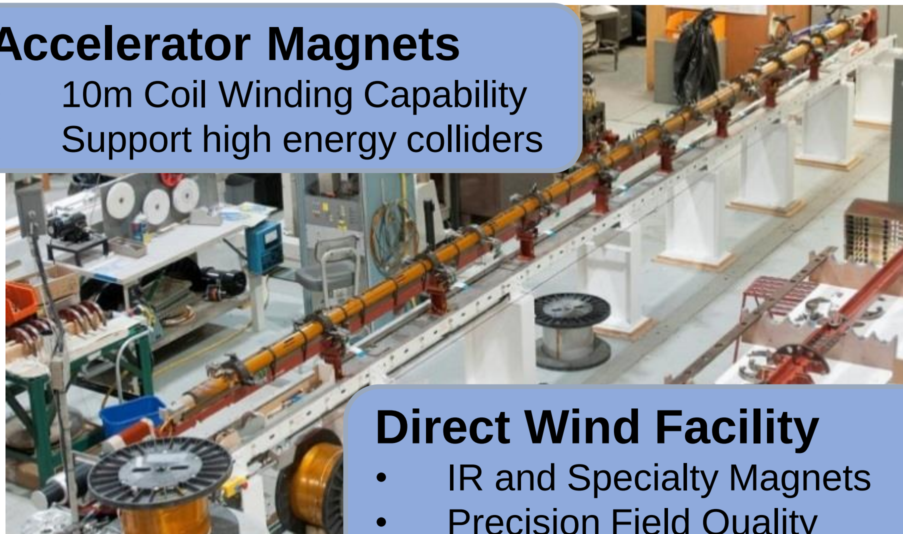


Superconducting Magnet Division

- **A world class superconducting and electromagnetics team creating the future of superconducting magnet technology**
- **Offering leadership in superconducting magnet technology, magnet development, manufacturing and testing**

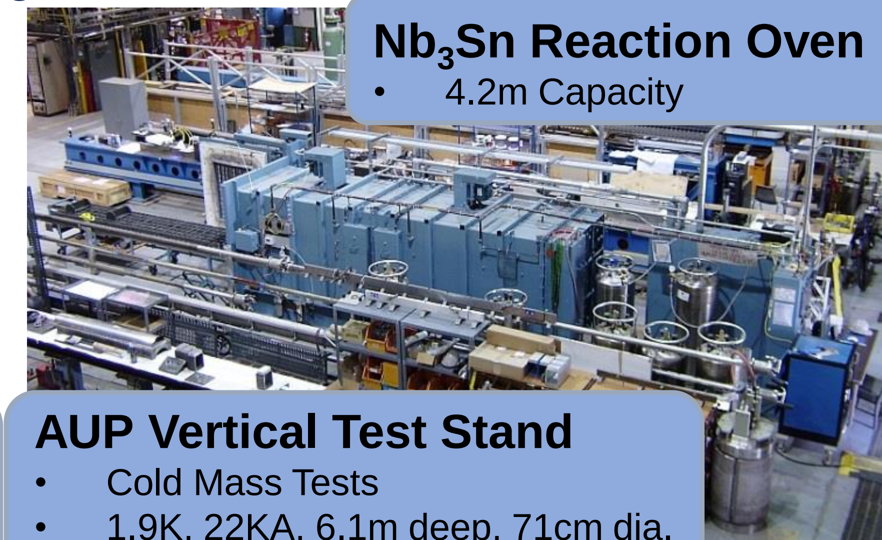
Accelerator Magnets

- 10m Coil Winding Capability
- Support high energy colliders



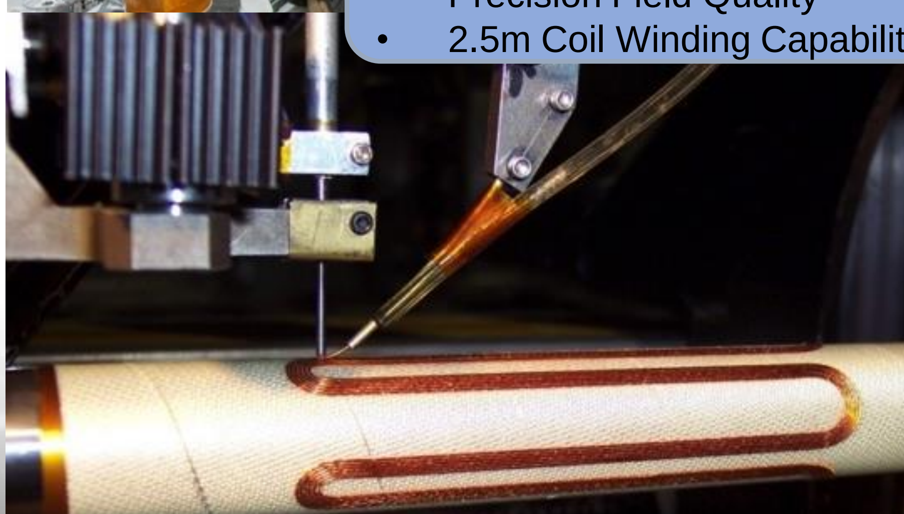
Nb_3Sn Reaction Oven

- 4.2m Capacity



Direct Wind Facility

- IR and Specialty Magnets
- Precision Field Quality
- 2.5m Coil Winding Capability

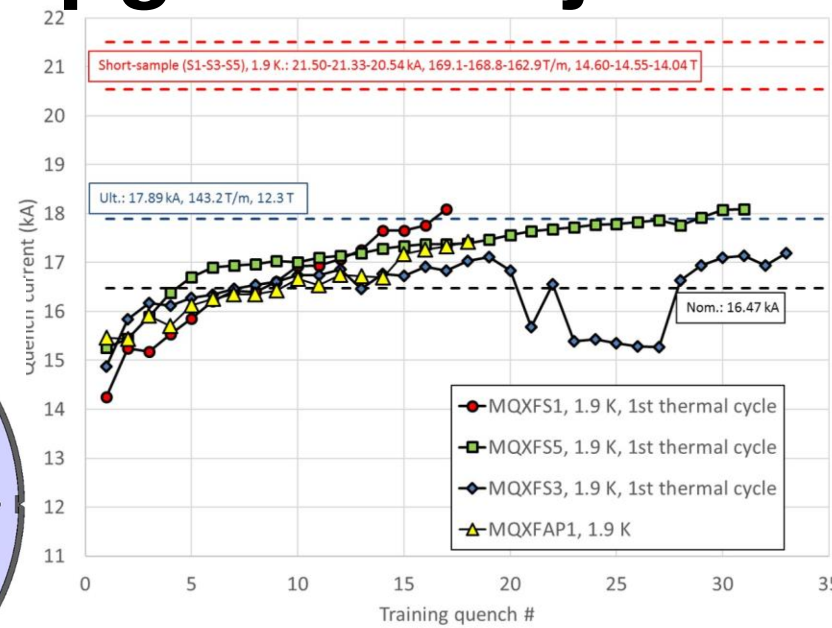


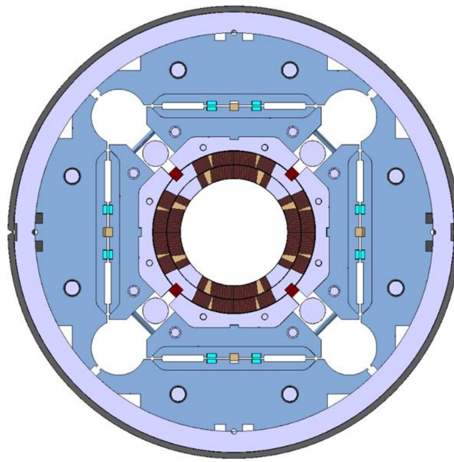
AUP Vertical Test Stand

- Cold Mass Tests
- 1.9K, 22KA, 6.1m deep, 71cm dia.

LARP ⇨ Accelerator Upgrade Project

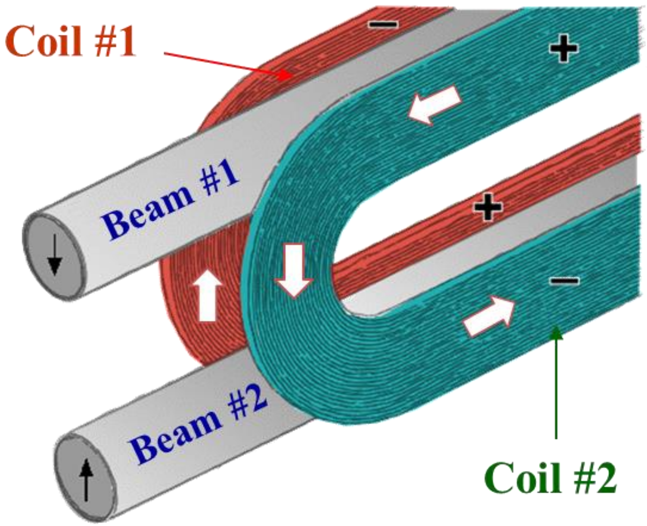
- BNL-SMD Scope
  - Manufacture 47 4.2m quad coils
  - Test 27 4.2 magnet cold masses

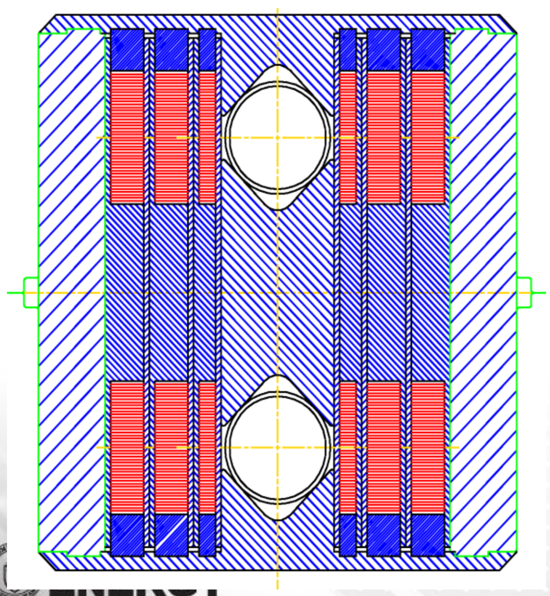




MQXFAP1 at BNL after shipment

A High Field Collider Dipole Design for HTS Coils

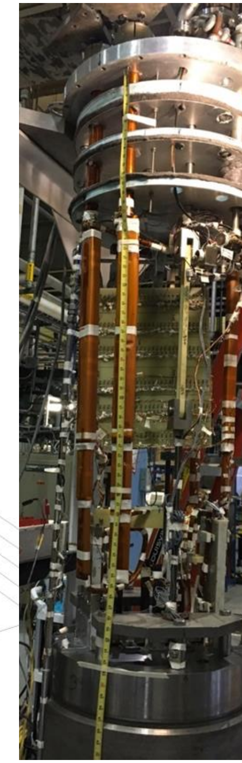


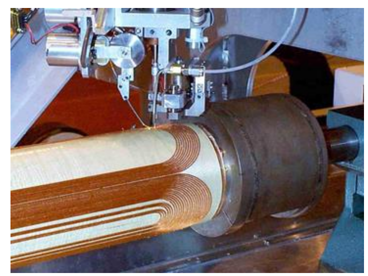


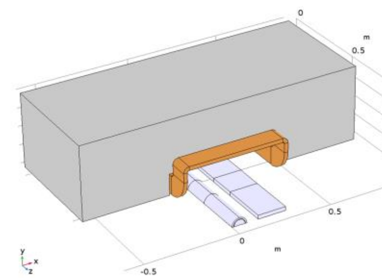
- Common coil 2-in-1 design with large bend radii (determined by the spacing between the two bores rather the size of the bore itself)
- Conductor friendly simple racetrack coils
- Coils move as a unit under large Lorentz forces
- Replaceable coil modules for flexible, low cost, systematic R&D

Further Opportunities for DOE Office of Science

- Present facility supports 5 vertical test stands:
  - 2 required for AUP magnet tests, which (at full production rate) will represent a ~25% duty cycle for the SMD cryoplant
  - 1 configured for conductor, cable and coil tests (including HTS) in the 10T Common Coil Magnet background field (MDP and CFS/FES partnership through INFUSE)
  - A 6th pit, capable of handling 1.5m diameter magnets also exists, which could be used for a test stand for the fusion industry (Commonwealth Fusion - CFS)
    - ***Represents unique leverage for combined NP/HEP/FES/CFS testing use***
- Capability to produce magnet designs and prototypes – both conventional SC magnets and direct wind
- Extensive testing and magnet characterization capability – utilized by NP and NSLS II
- Industry interest in capabilities – GE, UTRC, CFS, Small business and VC

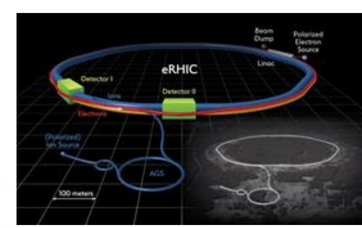







BROOKHAVEN Newsroom

U.S. Energy Secretary Honors Brookhaven Lab Team for Building Large Hadron Collider Magnets



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Partnerships with Others

- Work with other labs globally
- Industrial applications of superconductivity
  - Energy space
  - Compact fusion
  - High field magnets
  - Medical applications – Best Medical
  - Utilizing talent and capabilities to aid industry
- Continuing to develop and expand partnerships – becoming a larger percentage of portfolio

Conclusions

- Excited to be here and making a difference
- Expanding partnerships with the magnet industry and other agencies – UTRC, EERE, NYSERDA, …
- SMD – a strong history and a bright future with…
  - Addressing future infrastructure and staffing needs
  - Expanding exposure of BNL capabilities to magnet community
  - Enabling EIC and MDP success
  - Breaking down the stovepipes to enable the future of magnet technology in the US
  - Positions open!