The US Accelerator Magnet Programs

Soren Prestemon
Lawrence Berkeley National Laboratory

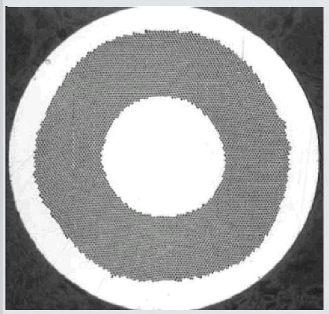
Outline

- A history of technology development
- Primary ongoing magnet programs
  - ➡ BNL focus areas
  - ➡ FNAL focus areas
  - ➡ LBNL focus areas
  - ➡ University programs
- The role of research programs in a big-project environment

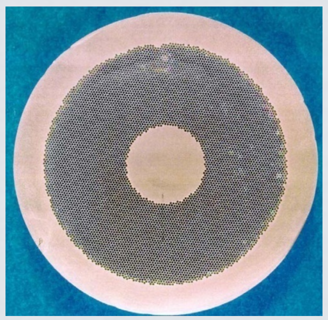
Technology development

Technology development

From conductor to magnets



NbTi LHC wire (A. Devred, [1])



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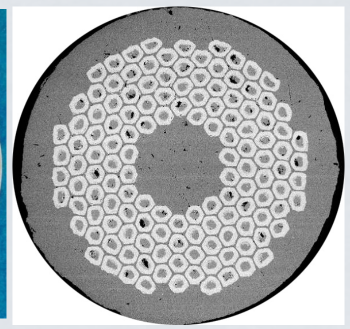

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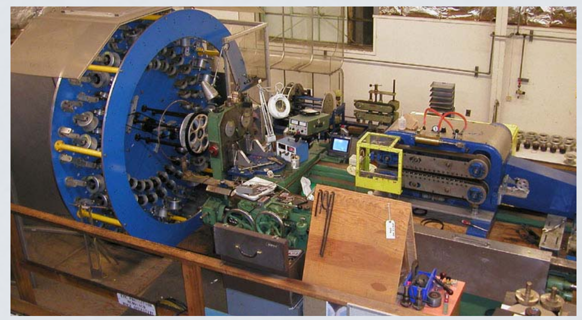
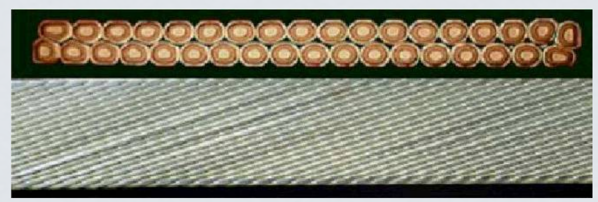
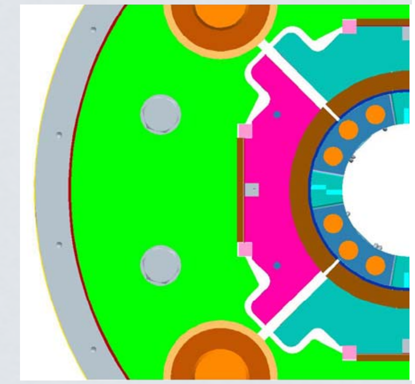
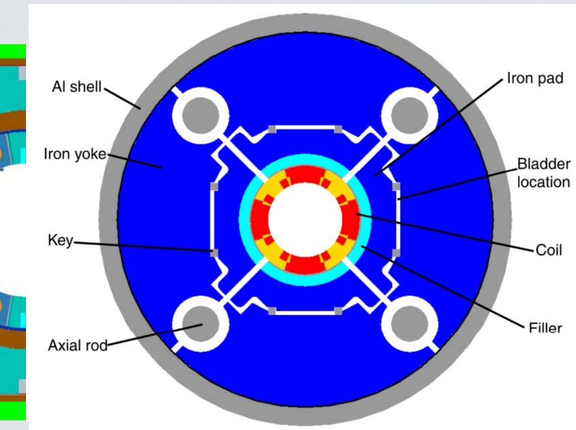
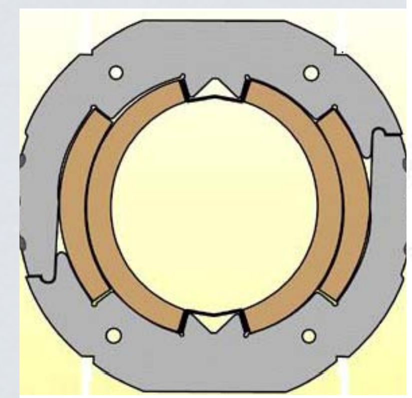


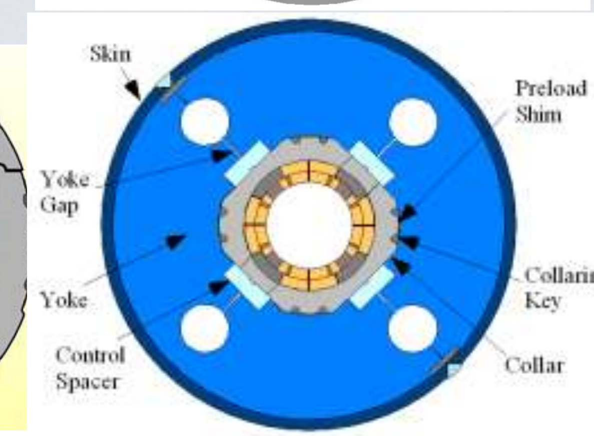


Conductor ⇨ Cable ⇨ Magnetic design ⇨ Structure design





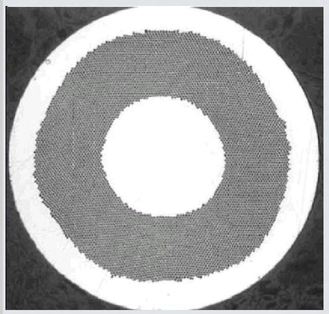




Coil fabrication ⇨ Magnet assembly ⇨ Magnet test

Technology development

From conductor to magnets



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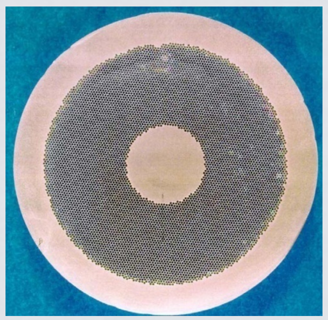

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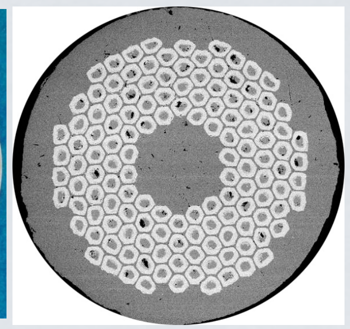

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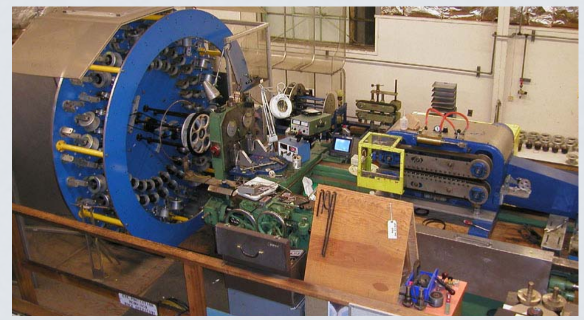

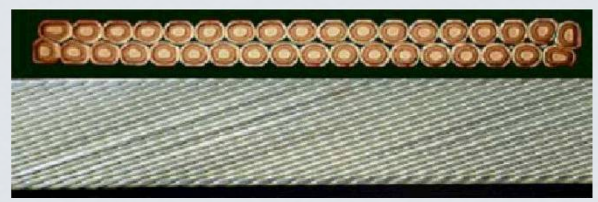

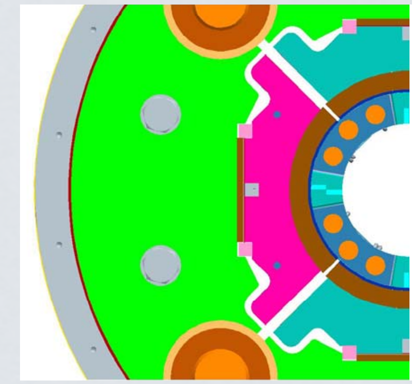

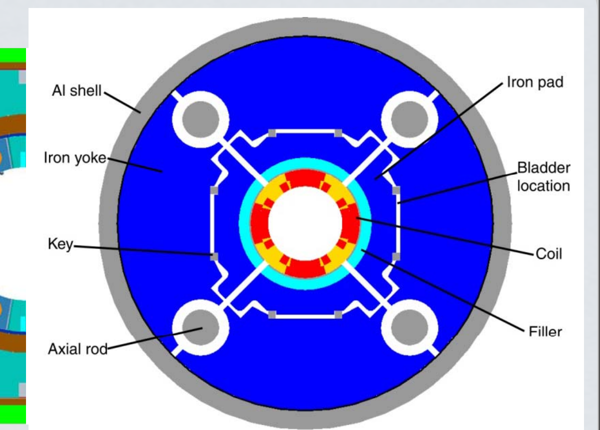

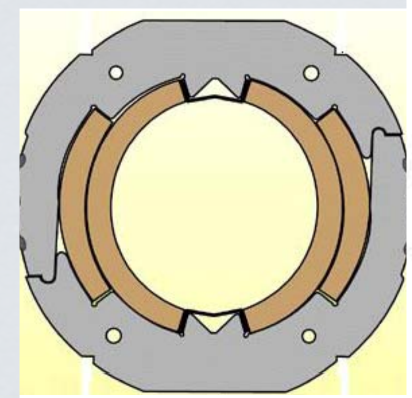

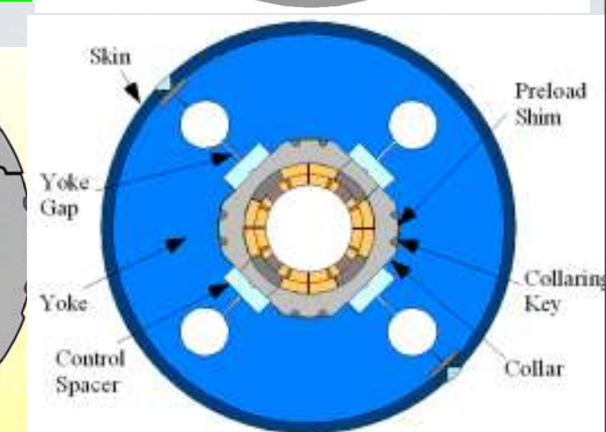

Conductor ⇨ Cable ⇨ Magnetic design ⇨ Structure design

Coil fabrication ⇨ Magnet assembly ⇨ Magnet test

Evolution of HEP rings...

⇨ **The next BIG machine!**

Technology impacts machines

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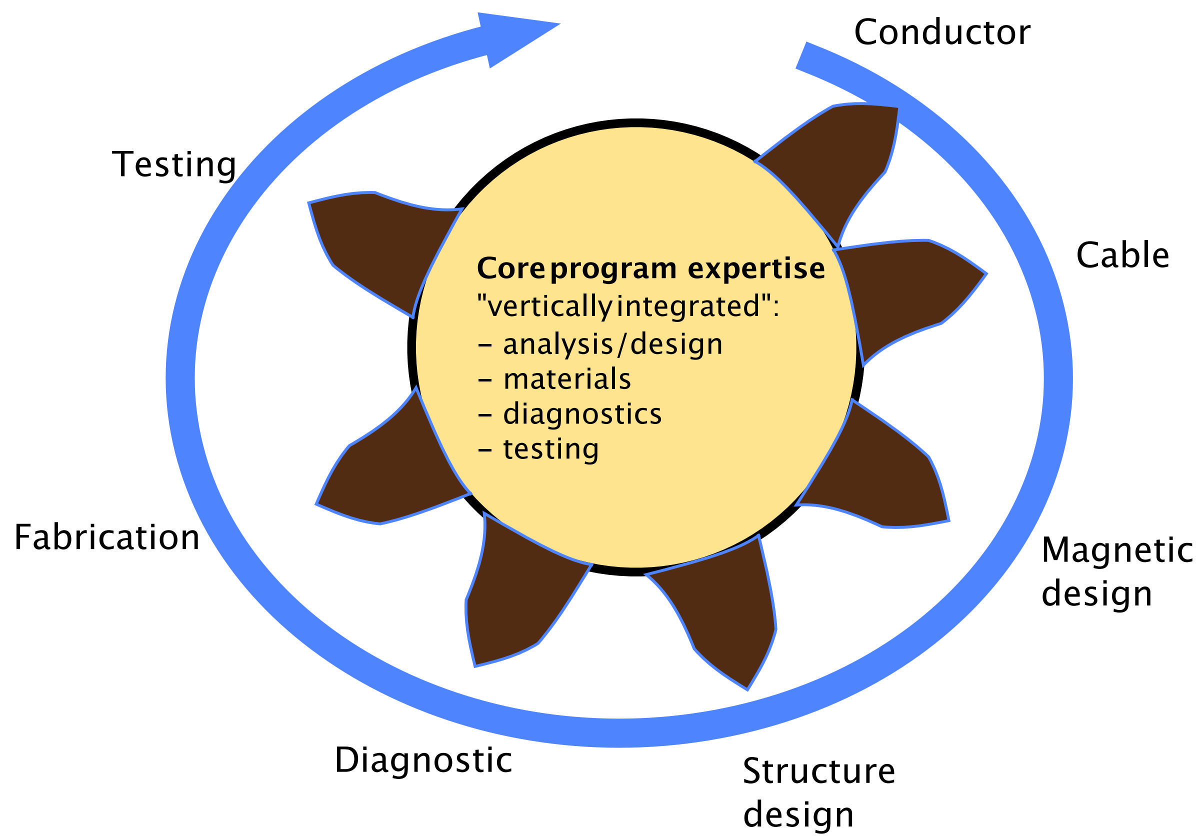

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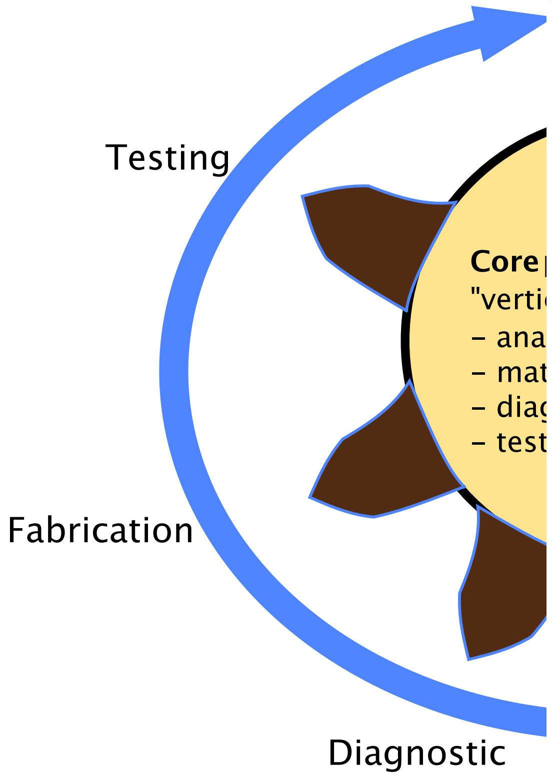

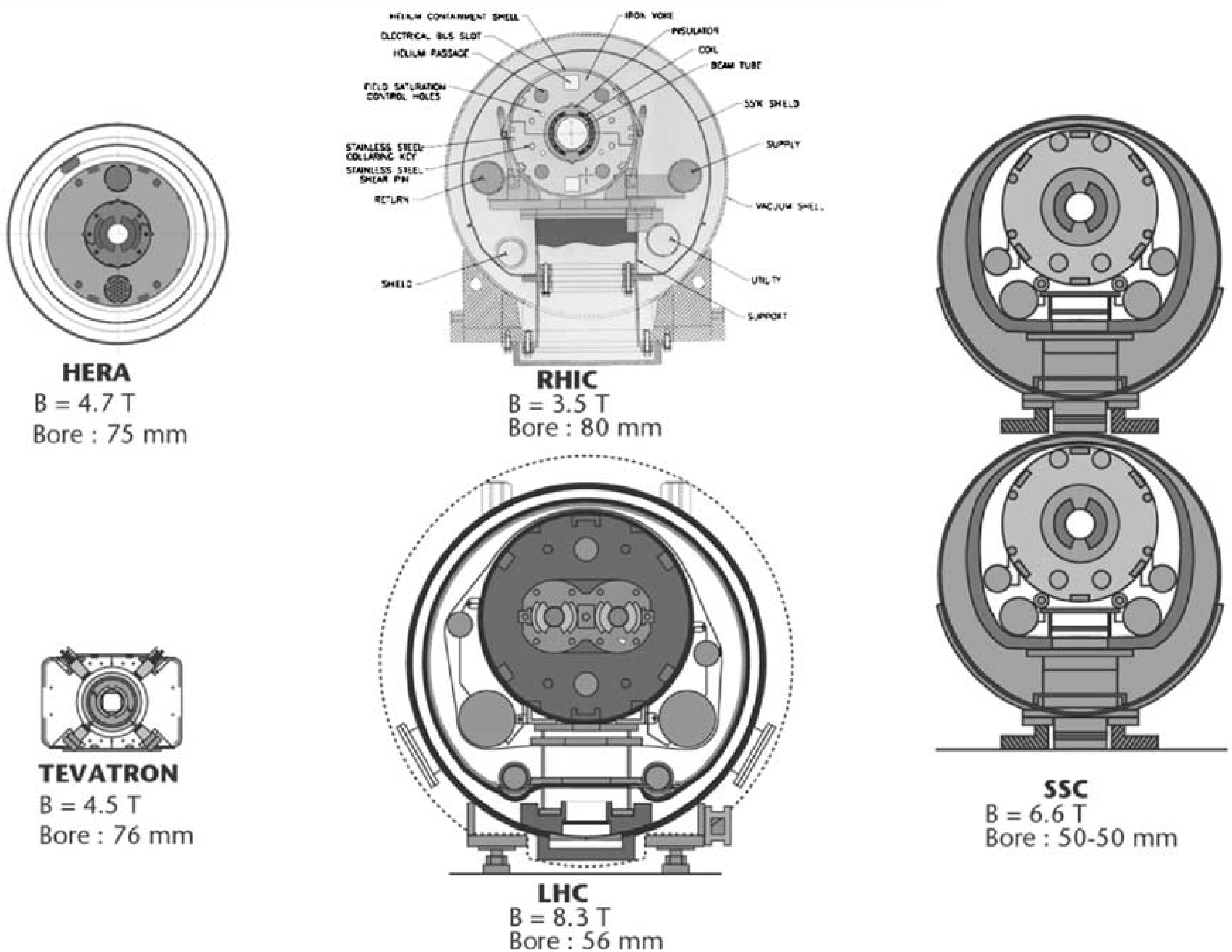

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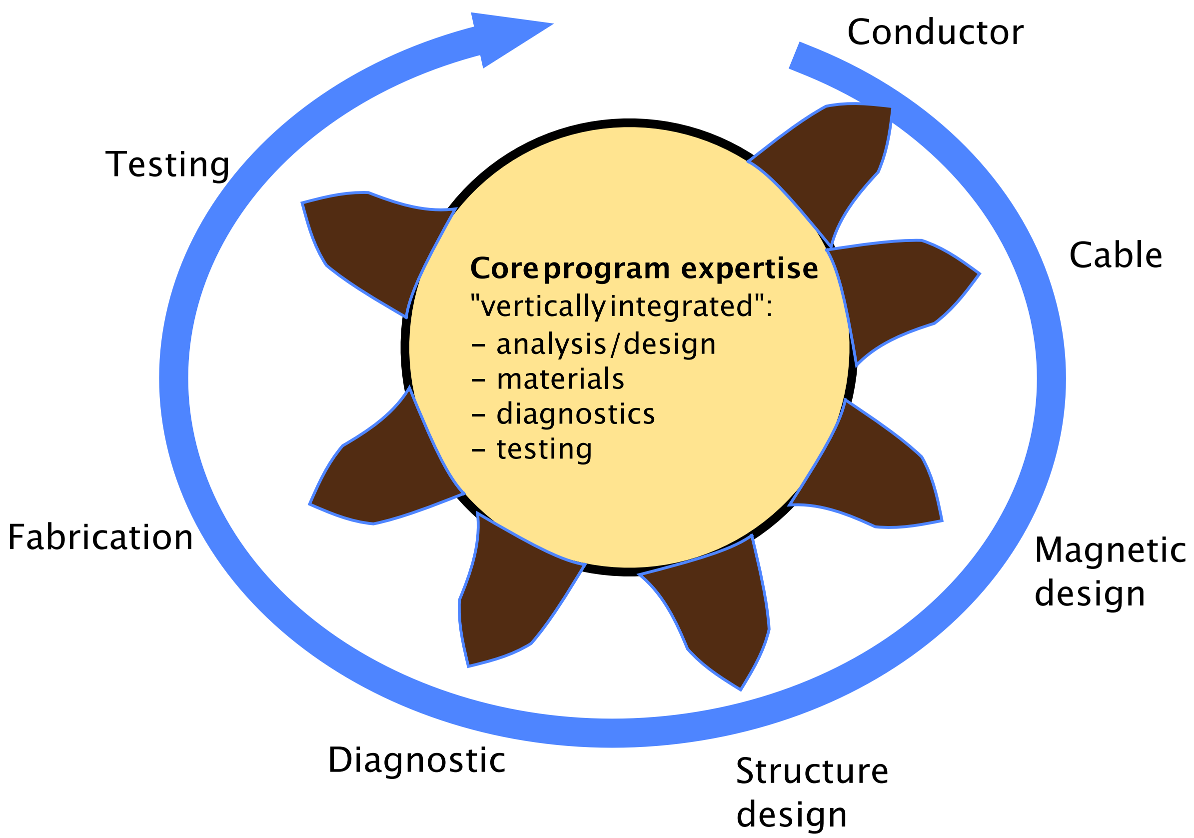

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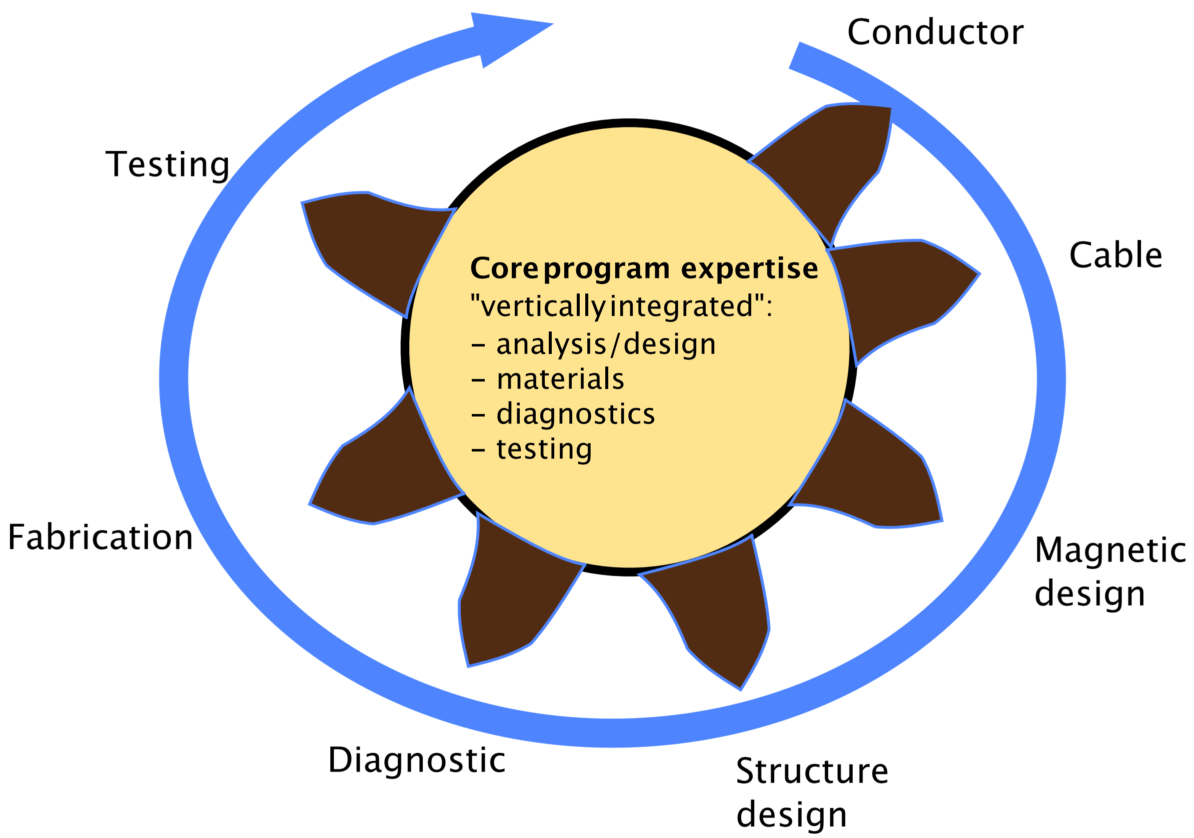
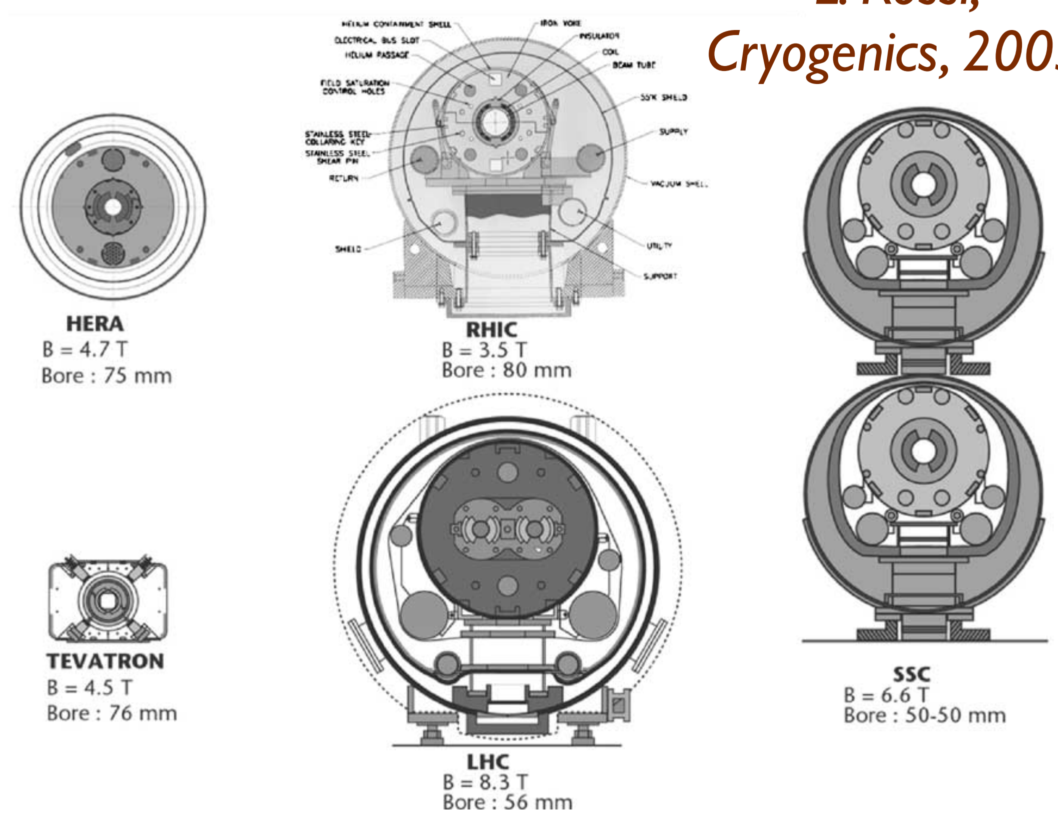


L. Rossi, Cryogenics, 2003



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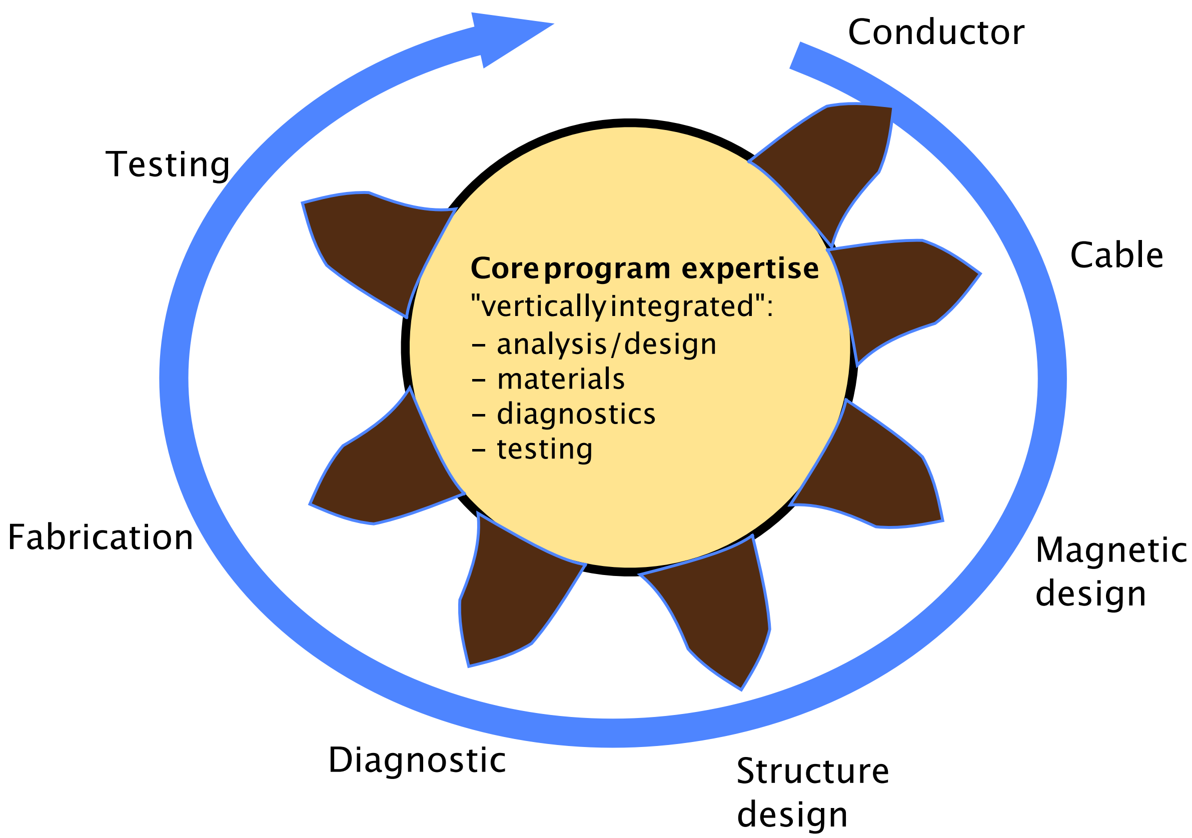

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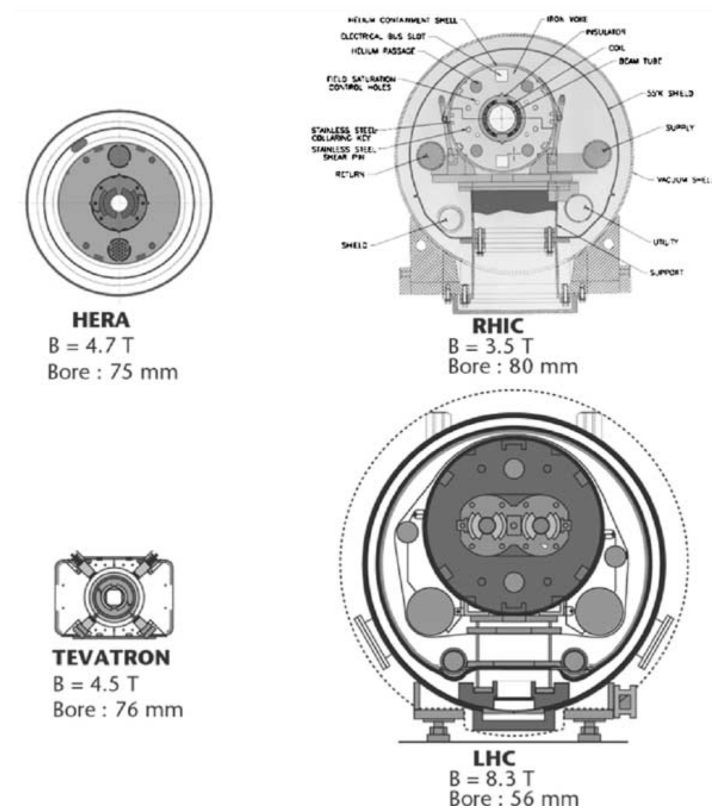

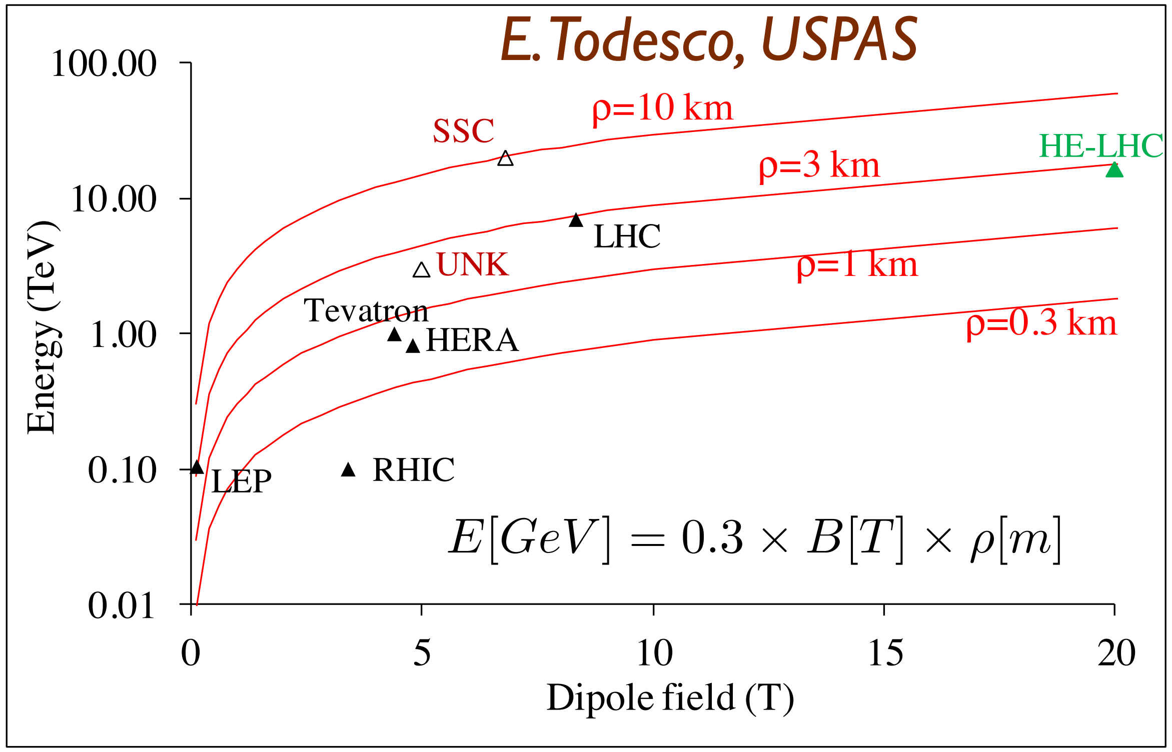

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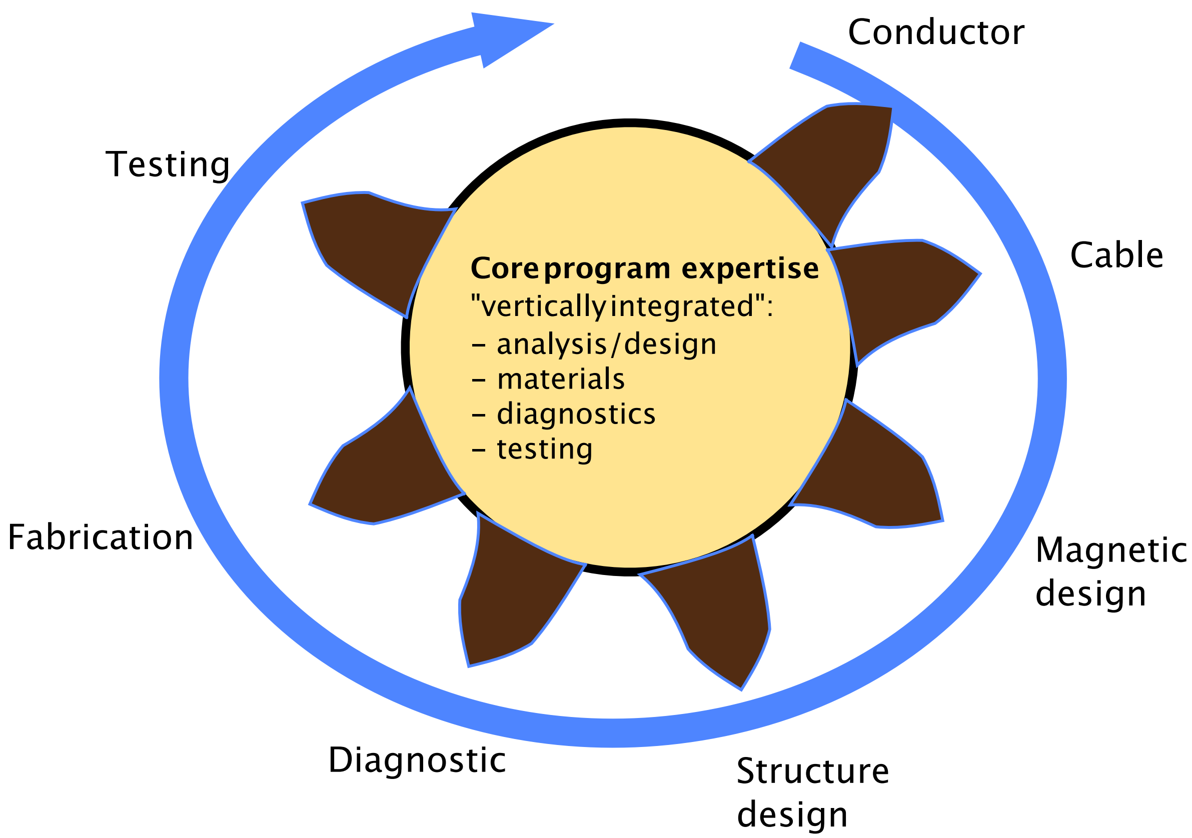

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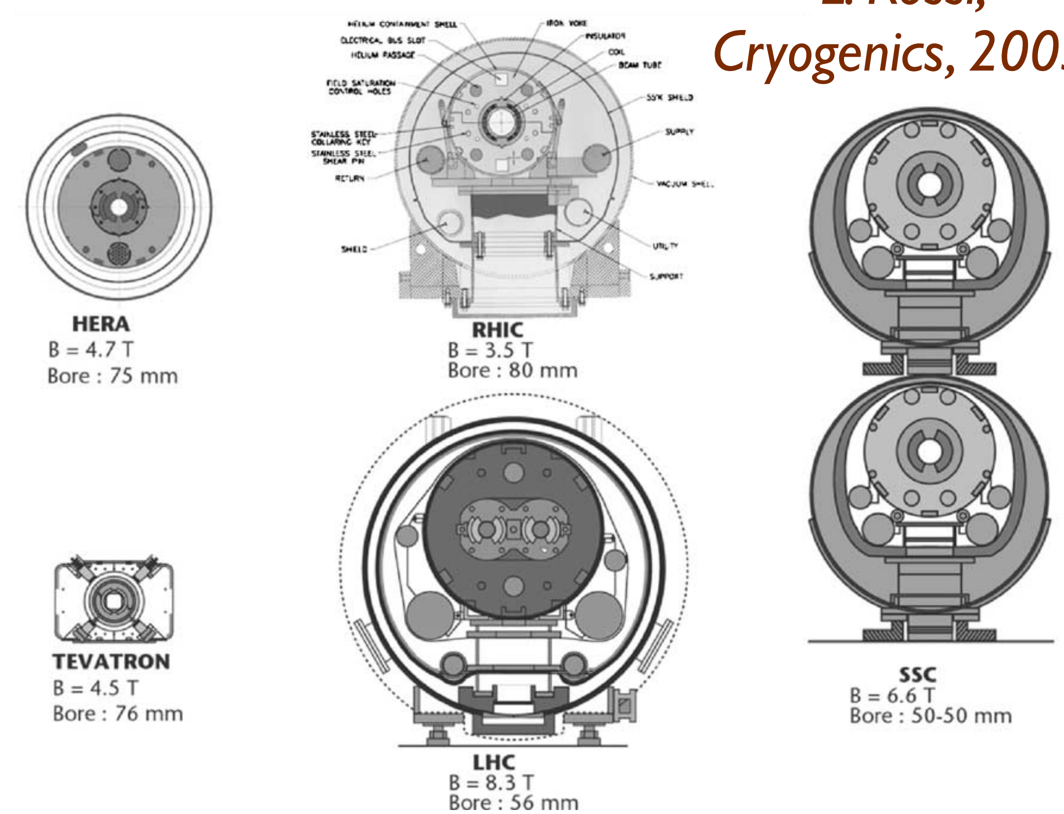
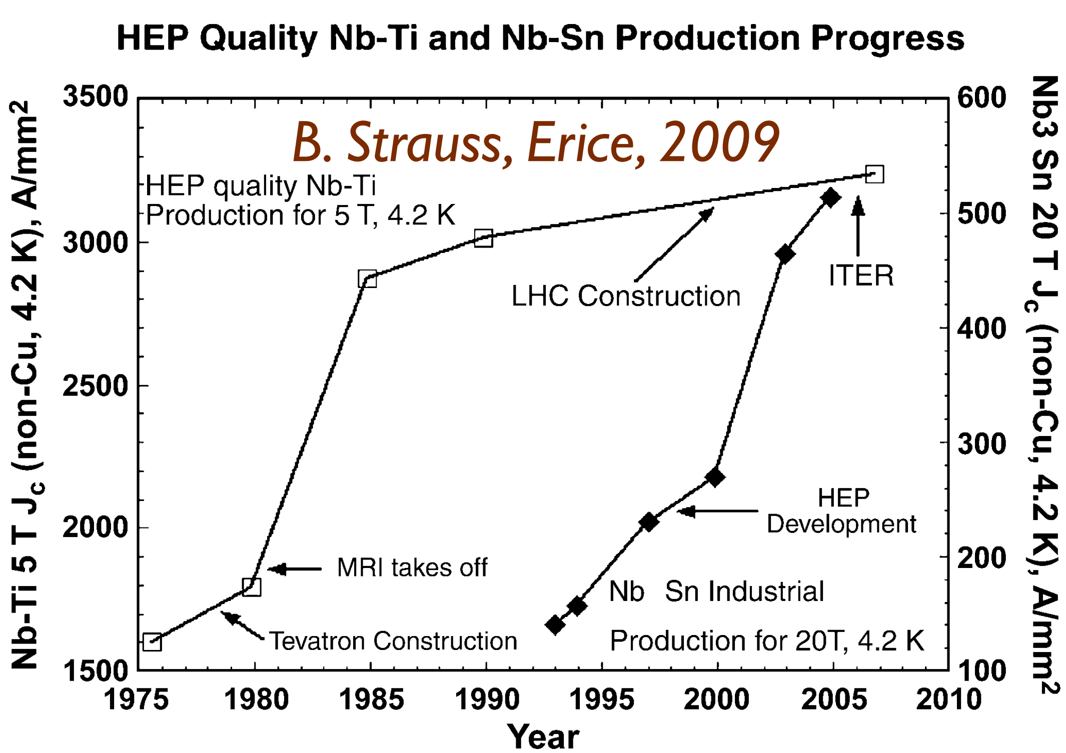
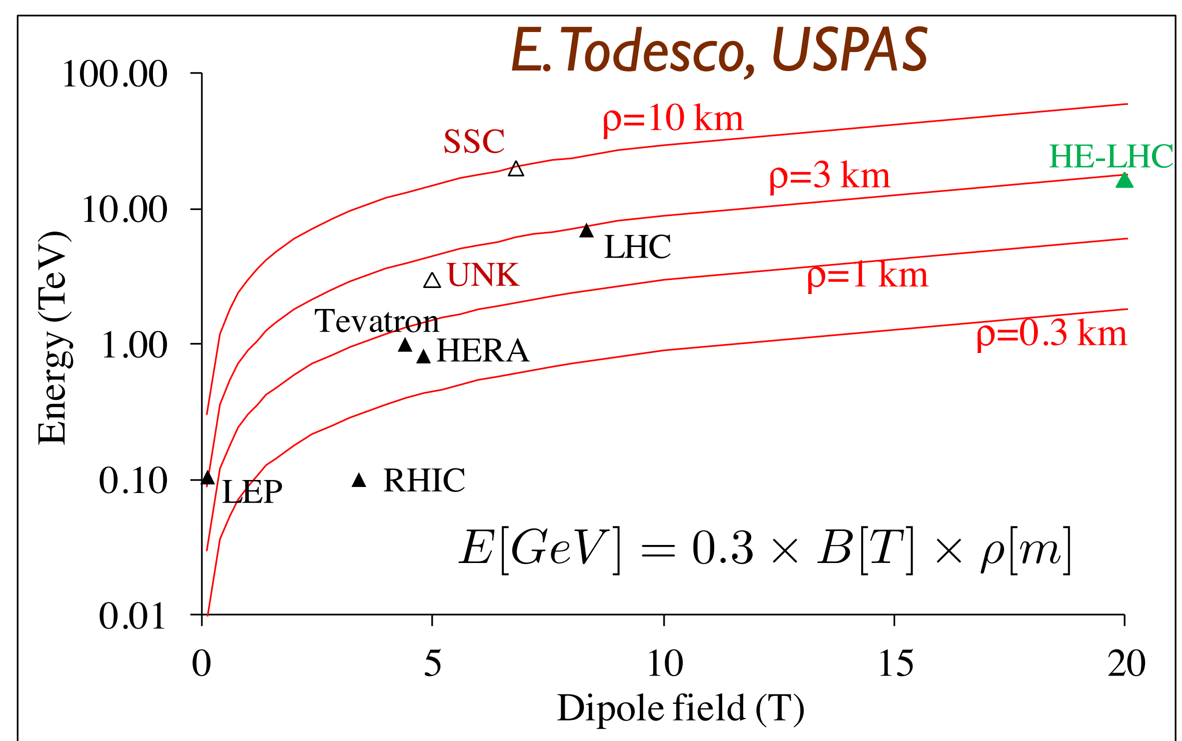


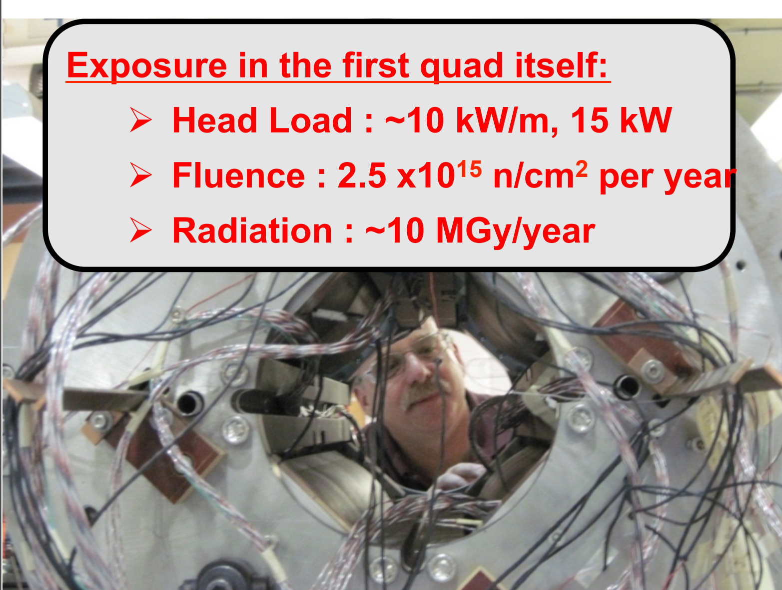


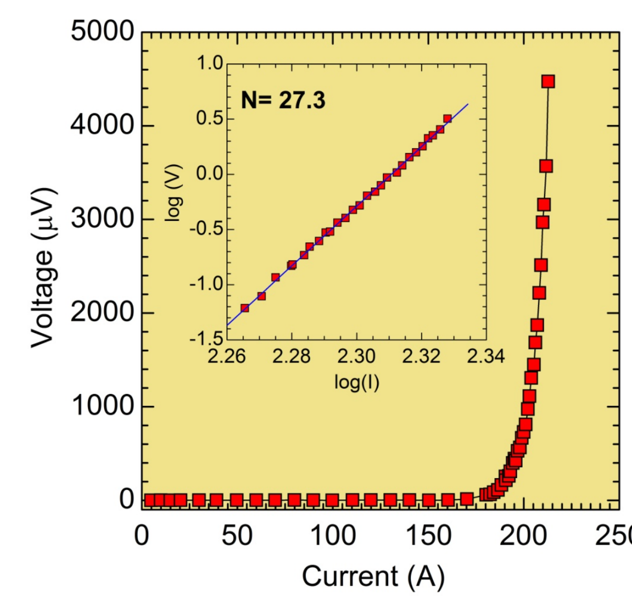


BNL Magnet Program

Courtesy Ramesh Gupta

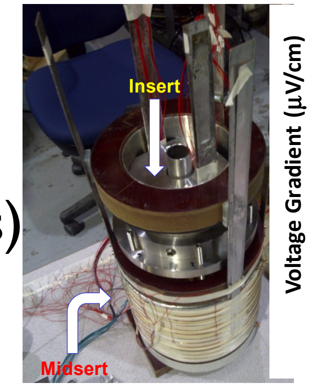
- Accelerator dipole and quadrupole magnet programs
  - ➡ HTS magnet is now part of the baseline design of a major proposed facility – Facility for Rare Isotope Beams (FRIB)
    - ✓ This is a significant 1st – perhaps a major milestone
  - ➡ High field magnets in a hybrid design for LHC upgrade
- High field solenoid programs
  - ➡ For Muon Collider and Energy Storage

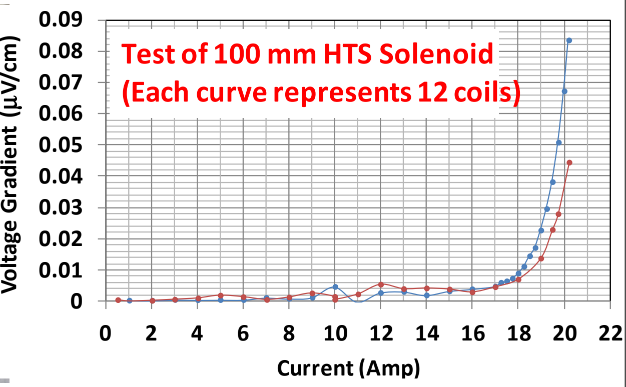




BNL major results

- HTS Quad for FRIB
  - ➡ made with 2G HTS from SuperPower and ASC
- HTS (YBCO) Cos(θ) demonstration
- Existing Common Coil Dipole at BNL for High Field HTS Magnet R&D
  - ➡ Unique 10+ T Nb3Sn common coil dipole with large open space
  - ➡ Ideal vehicle to do to R&D with coils made with either Rutherford cable using Bi2212 or Roebel cable using YBCO - both providing high current
  - ➡ An HTS racetrack coil can be tested with a fast turn-around to a field of up to 15 T on HTS coil (a first demonstration of concept)
- High Field Solenoid for MAP
  - ➡ Plan built on significant results from SBIR funded R&D last year:
  - ➡ Bo>15 T (record), Bpeak >16 T in full insert (25 mm, 14 pancakes)
  - ➡ Bo> 6 T, Bpeak > 9 T in half midsert (100 mm, 12 pancakes)
  - ➡ FY13-14 plan is to combine the two to create >20 T.
  - ➡ BNL advanced quench detection detects onset of very small pre-quench voltage in presence of large noise and inductive voltage.
  - ➡ Fabricated full midsert (24 pancakes). Successfully tested at 77 K.
  - ➡ Future program is to create >30 T with NbTi outsert





FNAL High-Field Magnet Program

Courtesy Sasha Zlobin

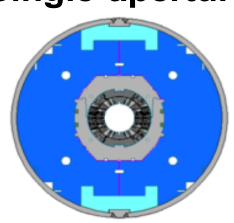
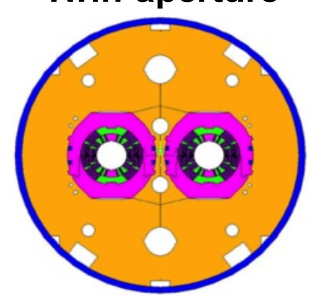
- ***The mission*** **of the High Field Magnet Program at Fermilab is the development of advanced superconducting *accelerator* magnets and baseline technologies for present and future particle accelerators.**
- ***At the present time the focus*** **is on the development of high-field accelerator magnets with operating fields up to 15 T based on Nb_3Sn superconductor.**
- ***In the longer term*** **the program will support the development of accelerator magnets with operating fields above 20 T.**

FNAL Major Results

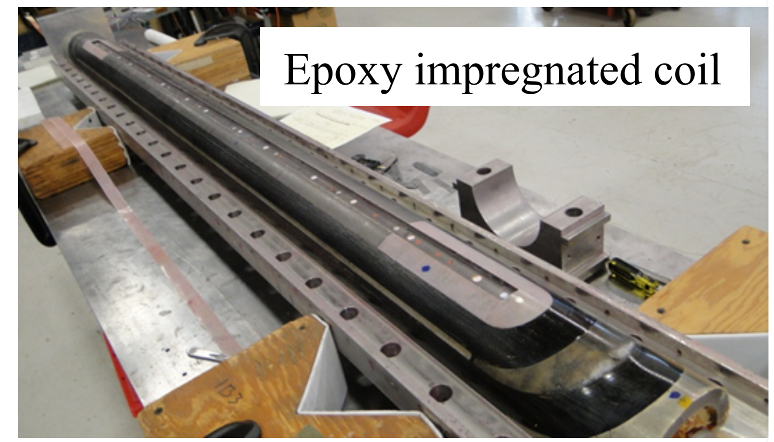
- FNAL HFM program developed and demonstrated
  - ➡ Rutherford cables based on Nb_3Sn, Nb_3Al and Bi-2212 strands (since 2000)
  - ➡ 43.5 mm Nb_3Sn dipoles for VLHC with operation fields up to 10-11 T (1998-2007)
  - ➡ 90-mm Nb_3Sn quadrupoles for LHC IRs with operation gradients up to 200 T/m (2005-2012)
  - ➡ Nb_3Sn coil technology scale up (2007-2011)
  - ➡ Helical solenoids for muon beam cooling (2007-2011)
- Started implementing Nb_3Sn magnets with magnetic fields up to 15 T into real machines, e.g. LHC, and work on radiation-hard magnets
  - ➡ 11 T dipole for LHC collimation system upgrade in collaboration with CERN (since 2010)
  - ➡ MATRIMID 5292 to replace epoxy as impregnation material for Nb_3Sn/Nb_3Al coils

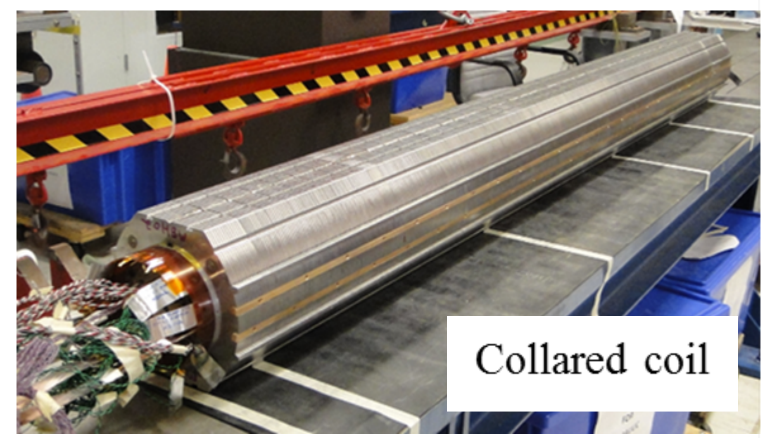
FNAL: Twin-aperture 11 T Nb_3Sn Dipole

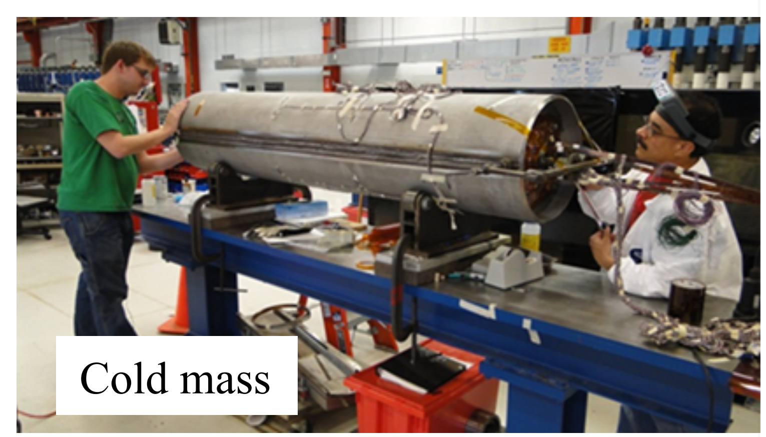
- **Collaboration with CERN for possible use in LHC**
  - **2012: 2-m long single-aperture demonstrator**
    - Magnet assembled and tested, B_{max}=10.4 T at 1.9K
  - **2013: 1-m long twin-aperture model**
    - First aperture assembled and being tested
    - Fabrication of the second aperture has started
  - **2014: 2-m long twin-aperture demonstrator**
  - **2015: 5.5-m long prototype**

Parameter	Single-aperture 	Twin-aperture 
Aperture	60 mm	
Yoke outer diameter	400 mm	550 mm
Nominal bore field @11.85 kA	10.86 T	11.25 T
Short-sample bore field at 1.9 K	13.6 T	13.9 T
Margin B_{nom}/B_{max} at 1.9 K	0.80	0.81
Stored energy at 11.85 kA	473 kJ/m	969 kJ/m
F_x per quadrant at 11.85 kA	2.89 MN/m	3.16 MN/m
F_y per quadrant at 11.85 kA	-1.57 MN/m	-1.59 MN/m

40-strand keystoned cable







LBNL Superconducting Magnet Program: Mission

- High Field Magnet Technology:
  - Maintain and further develop world class accelerator magnet design capabilities - leader in high-field magnet performance
  - Develop and establish the technologies associated with high-field accelerator magnets

    - **Materials**: superconductors, insulation, structural
    - **Coil designs**: efficiency, conductor compatibility
    - **Structures** to handle large forces and stresses
    - **Design, analysis and diagnostics** tools

- Apply our Capabilities to HEP Strategic Goals:
  - Provide critical contributions to LARP and LHC upgrades (e.g. Hi-Lumi)
  - Prepared to provide support to Muon collider R&D
  - Provide state-of-the-art superconducting magnet expertise to HEP Stewardship areas

LBNL SMP major results

- **Materials**
  - ➡ Manage DOE Conductor Development Program
    - ✓ coordinated effort among DOE labs to focus conductor improvements
    - ✓ dramatic improvements in Jc(12T)
  - ➡ Lead role in measuring and understanding strain-dependence in Nb_3Sn
- **Technology development**
  - ➡ Bladder-and-key concept for coil pre-stressing: now baseline for LARP
  - ➡ Quench protection heater and voltage tap "Trace", now standard on all LARP and high-field dipole magnets
  - ➡ Rutherford cable expertise: long history of NbTi and Nb_3Sn cables, primary supplier for LARP, first to make Bi2212 cables
- **Magnet development**
  - ➡ Lead in high-field dipole magnet development since 1997 (D20; RD3b; HD1)
  - ➡ Critical role in LARP: Conductor, Cable, Design, Structure, Assembly, Test; Management
  - ➡ Developed dipole subscale models to speed up concept testing
  - ➡ Investigation of Bi2212 racetrack concepts and technologies
  - ➡ Fast-DAQ diagnostics providing time-resolved quench-initiation and propagation data

LBNL: Areas of strength

- High field magnet technology leader
  - ➡ *Expertise in superconducting materials*
    - ✓ Oversee DOE Conductor Development Program
    - ✓ Leader in Rutherford cabling: NbTi, Nb3Sn, Bi2212
  - ➡ *Expertise in analysis/modeling*
    - ✓ *Integrated 3D analysis*

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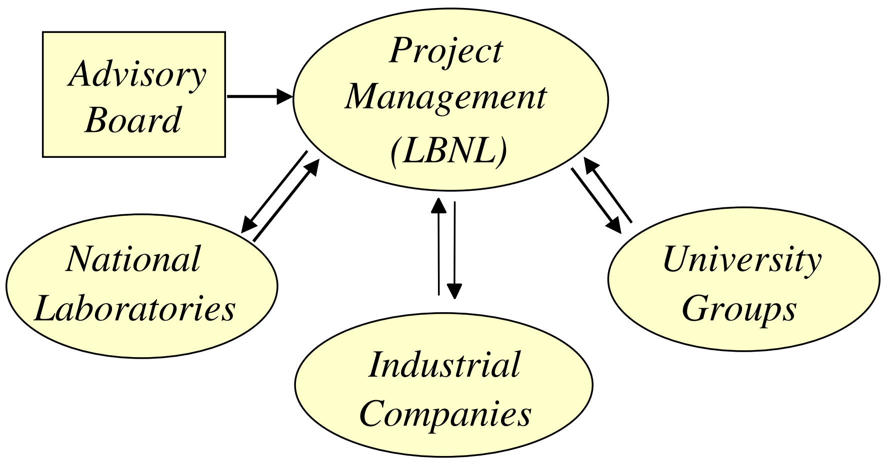

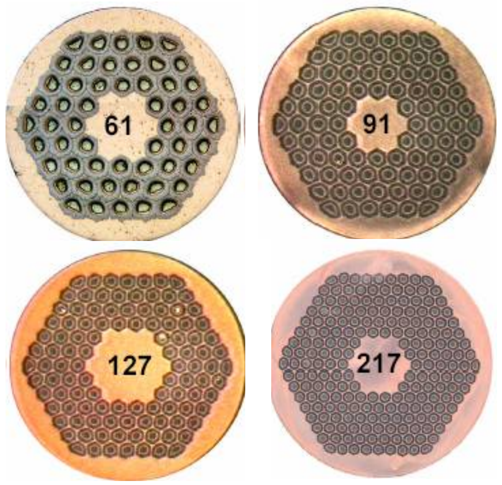

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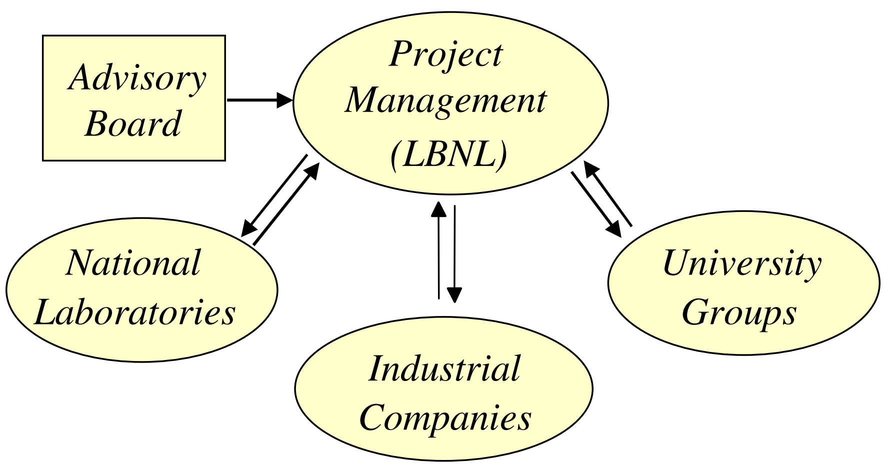

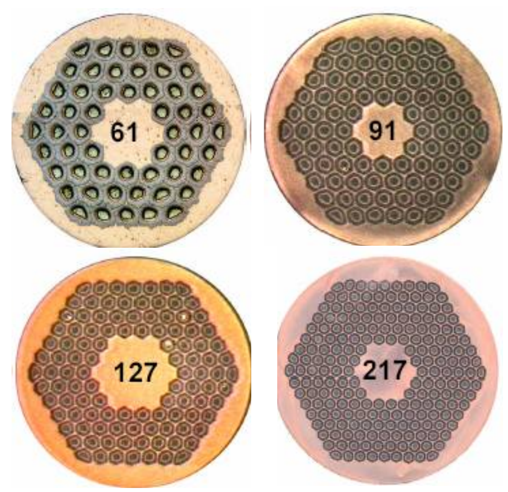

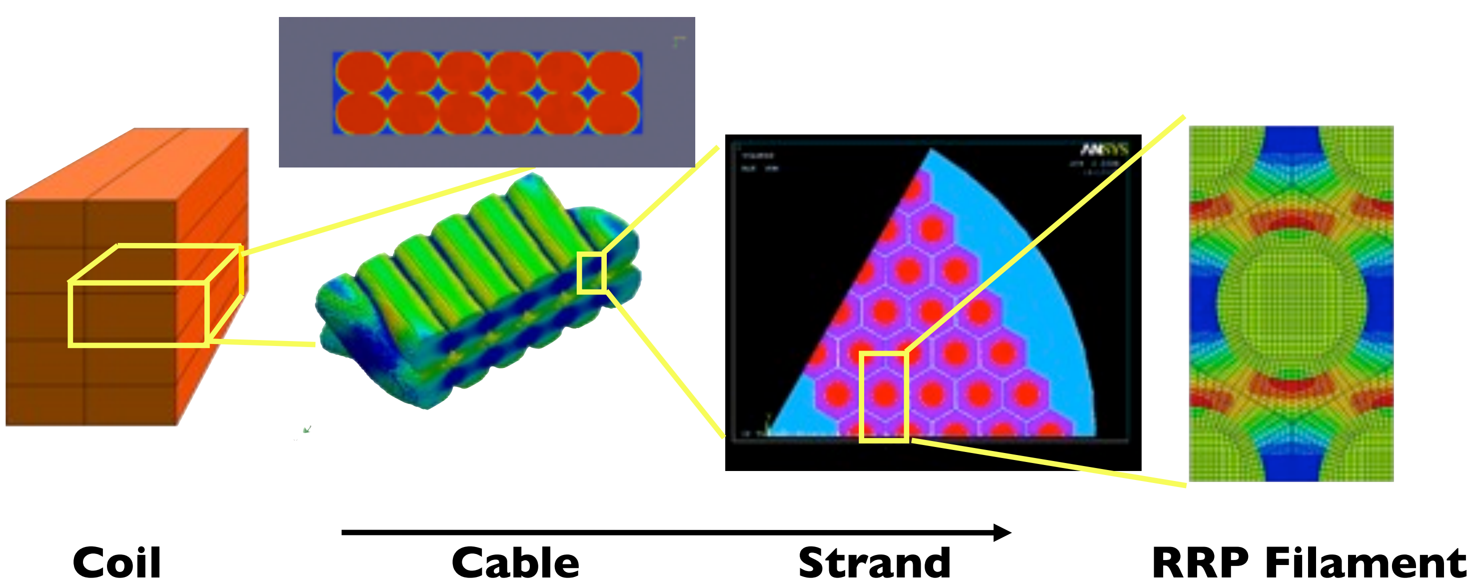

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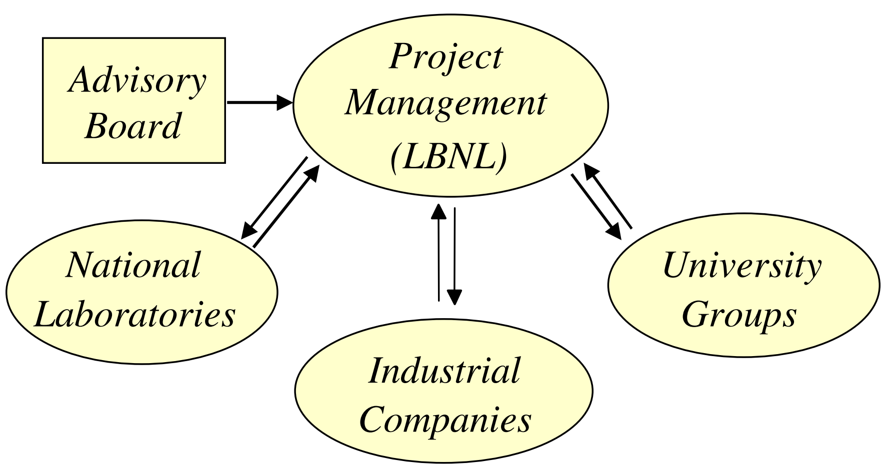

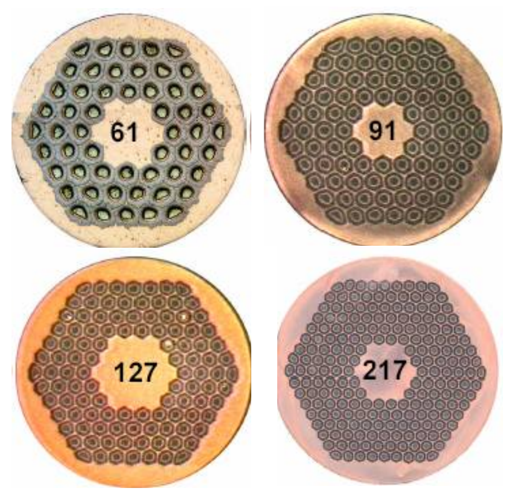

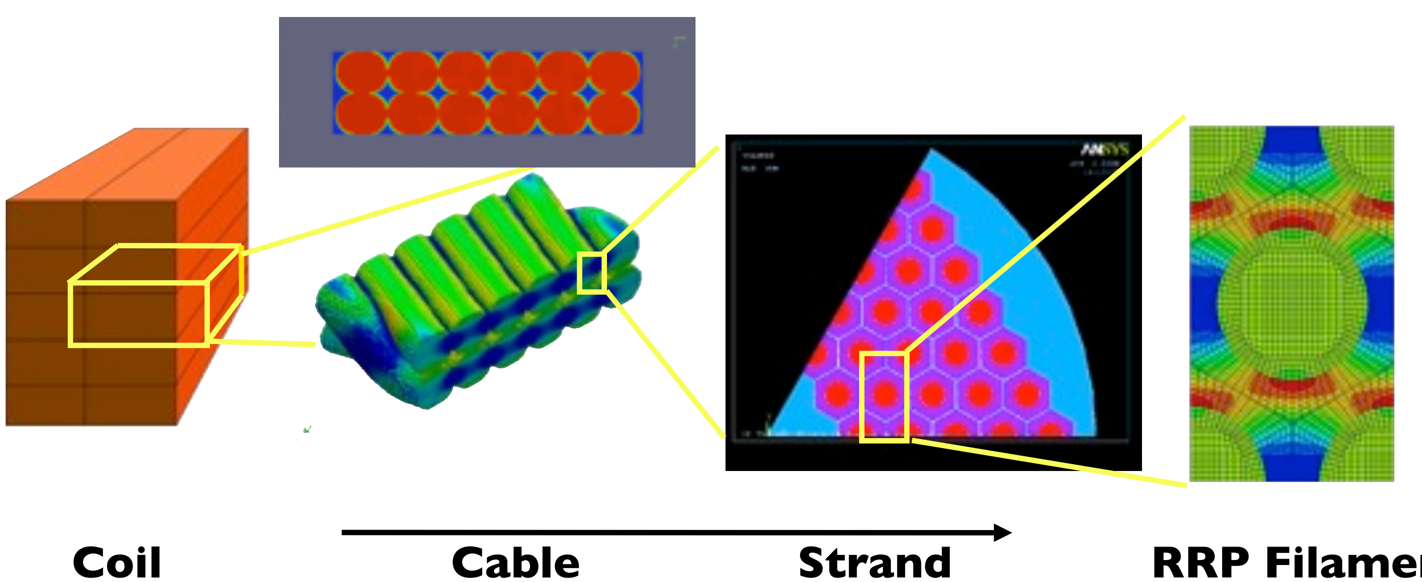

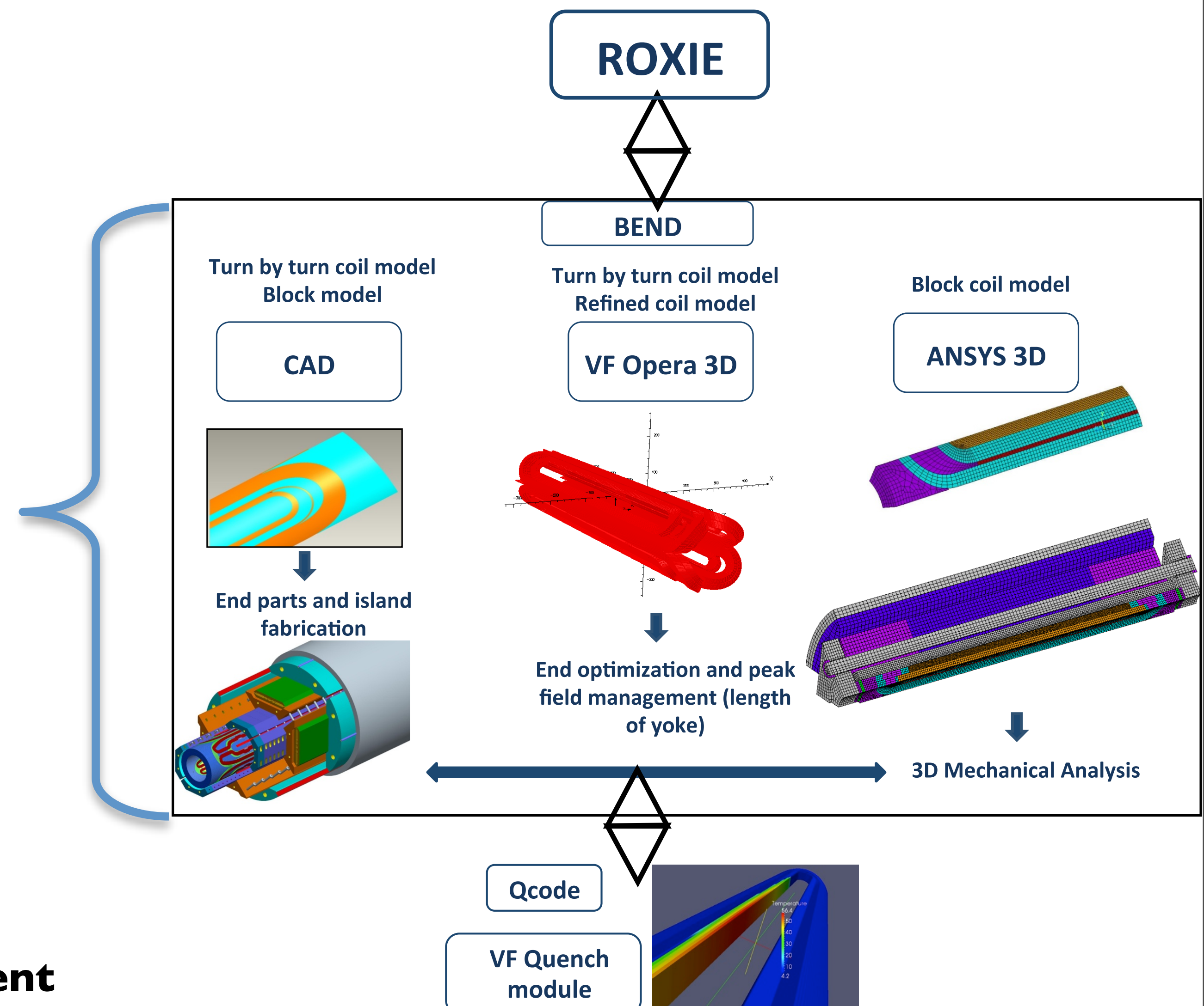

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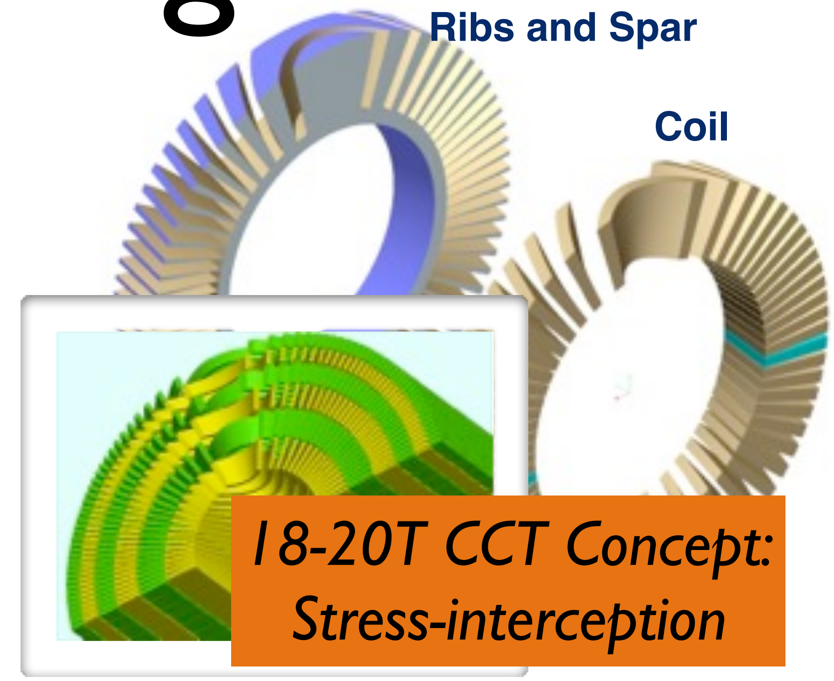
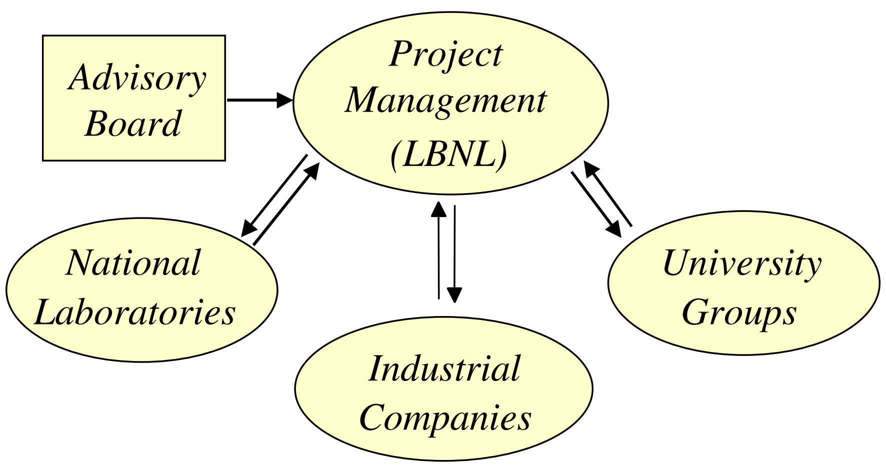
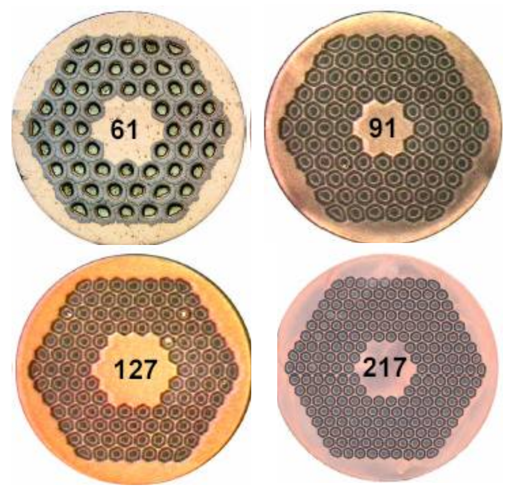
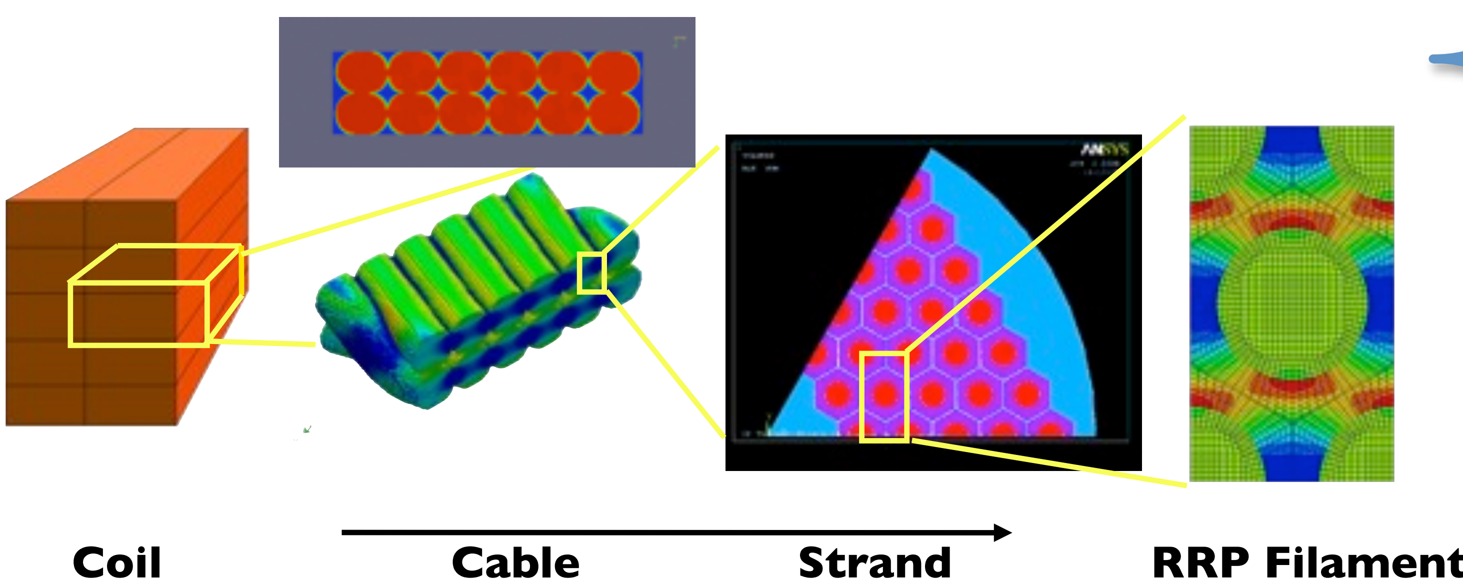
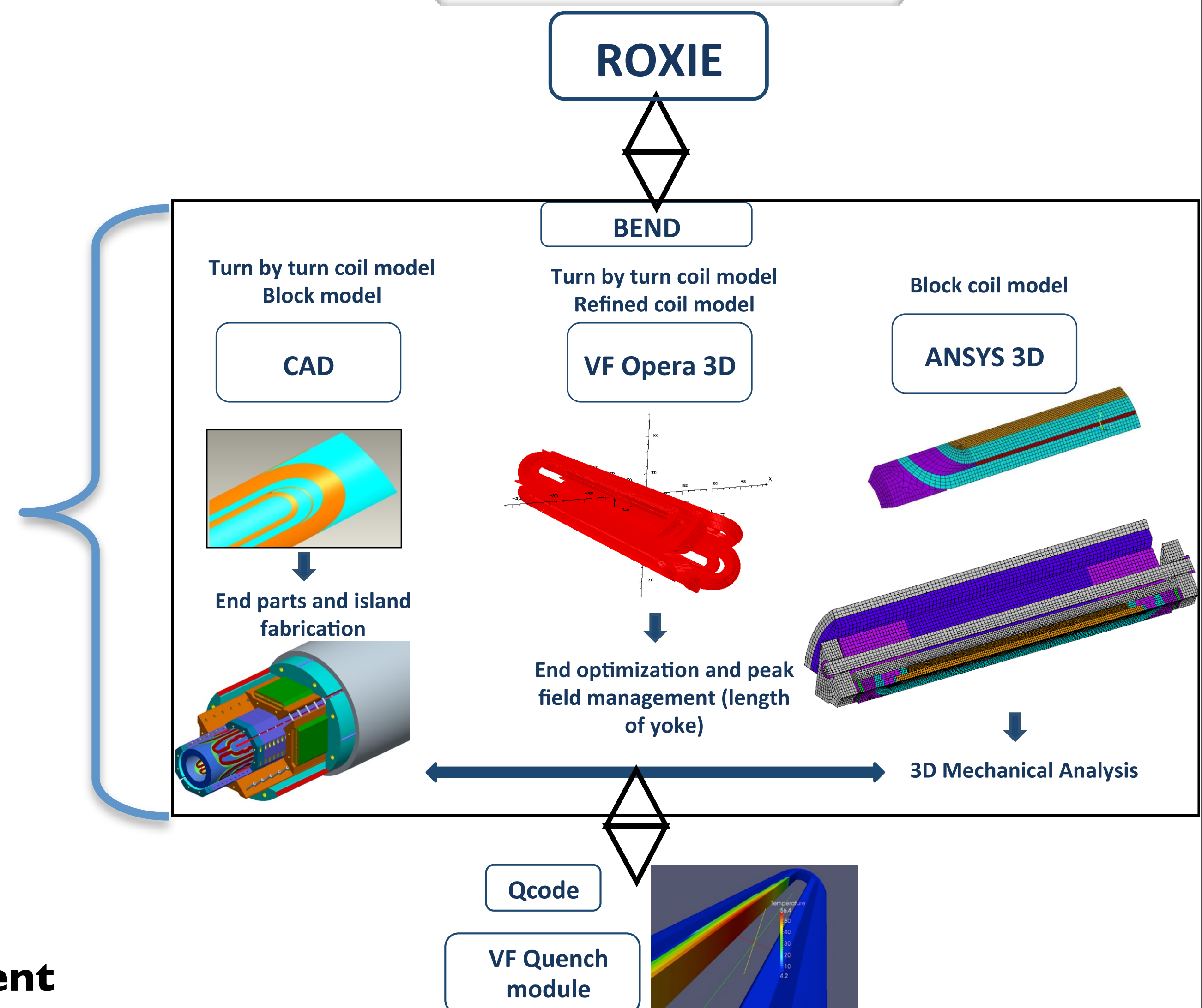




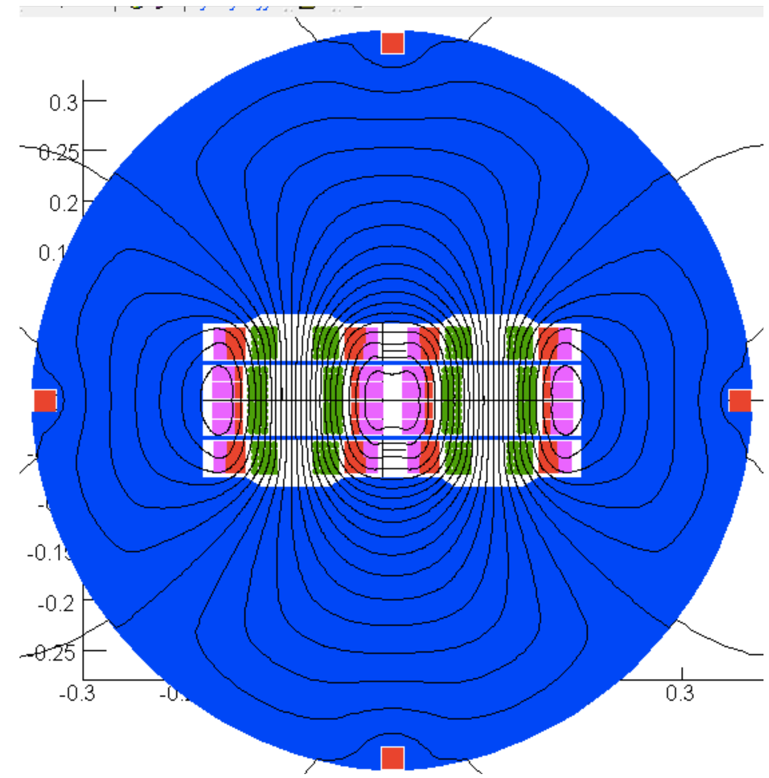






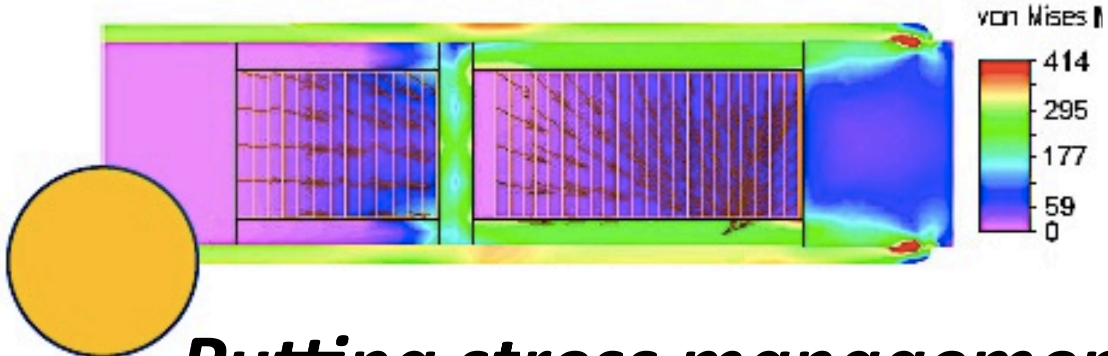
University Program: Texas A&M

- Nb3Sn and Bi-2212 Coil Technology for a >20 T LHC Energy Upgrade
  - ➡ The goal: >20 T dual dipole in ~same size cryostat as LHC dipole
  - ➡ 20 T 40 TeV collision energy – the SSC at last!
  - ➡ Clearing electrodes in the bore ...
    - ✓ eliminate electron cloud for ultimate luminosity
- Enabling technologies at Texas A&M:
  - ➡ Stress management in the windings
  - ➡ ***Bi-2212 structured cable***
  - ➡ ***Textured-powder Bi-2212 wire development***



Bore field (short sample)	21	T
Coil current	15	kA
Aperture	50	mm
Maximum winding stress:		
Nb_3Sn outer	140	MPa
Bi-2212 inner	90	MPa
Coil winding area:		
Nb_3Sn outer	52	mm^2
Bi-2212 inner	14	mm^2

Texas A&M: Major results

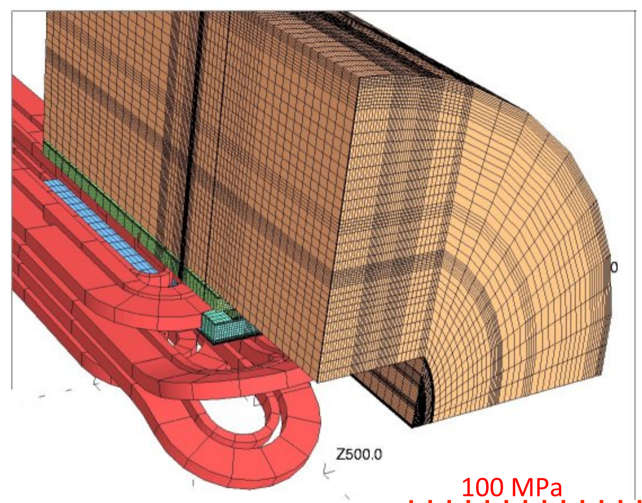


Lorentz stress can degrade current density in superconducting wires:
>100 MPa can degrade Nb_3Sn
>100 MPa can degrade Bi-2212/Ag

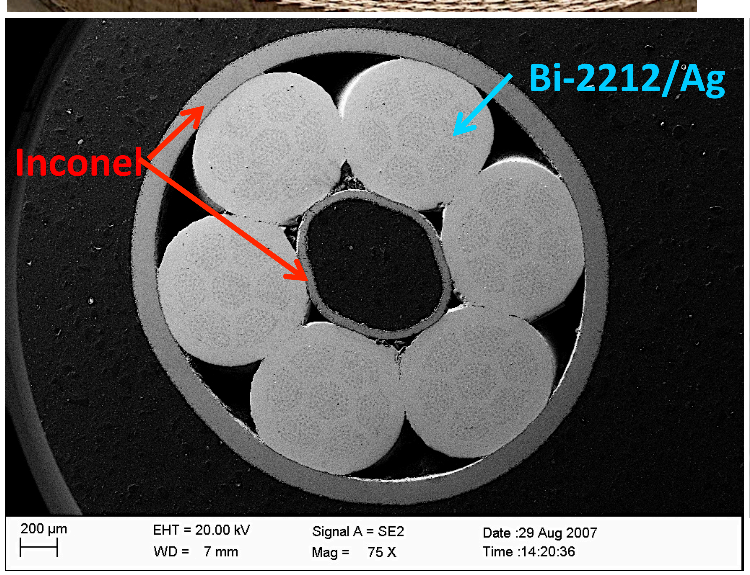
Putting stress management into practice

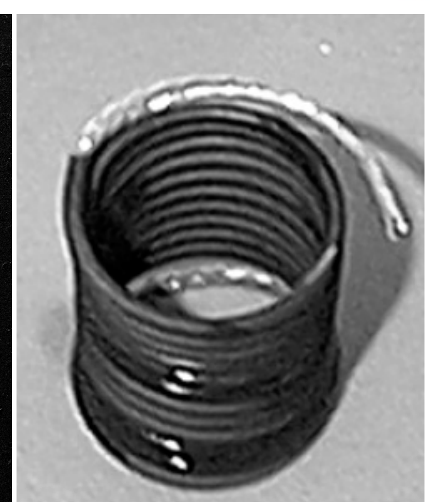
TAMU3 – 14 T racetrack dipole ***TAMU5 – 15 T flared-end dipole***

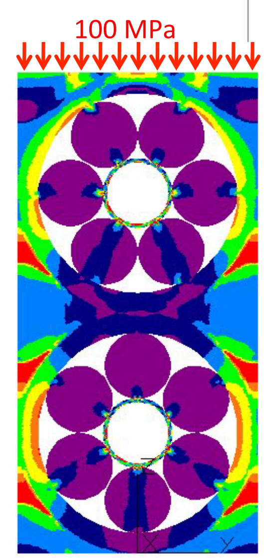
will test in summer 2013

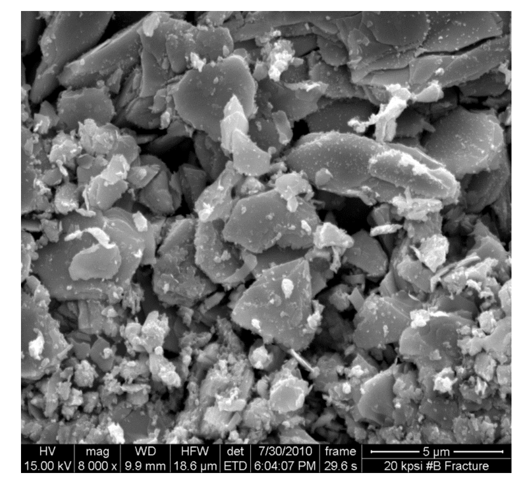


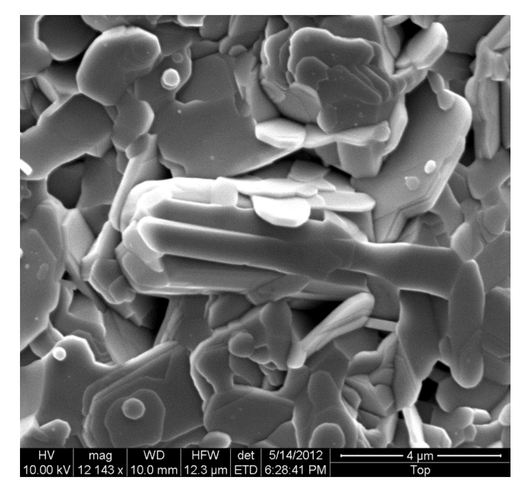
Dissertation – Trey Holik











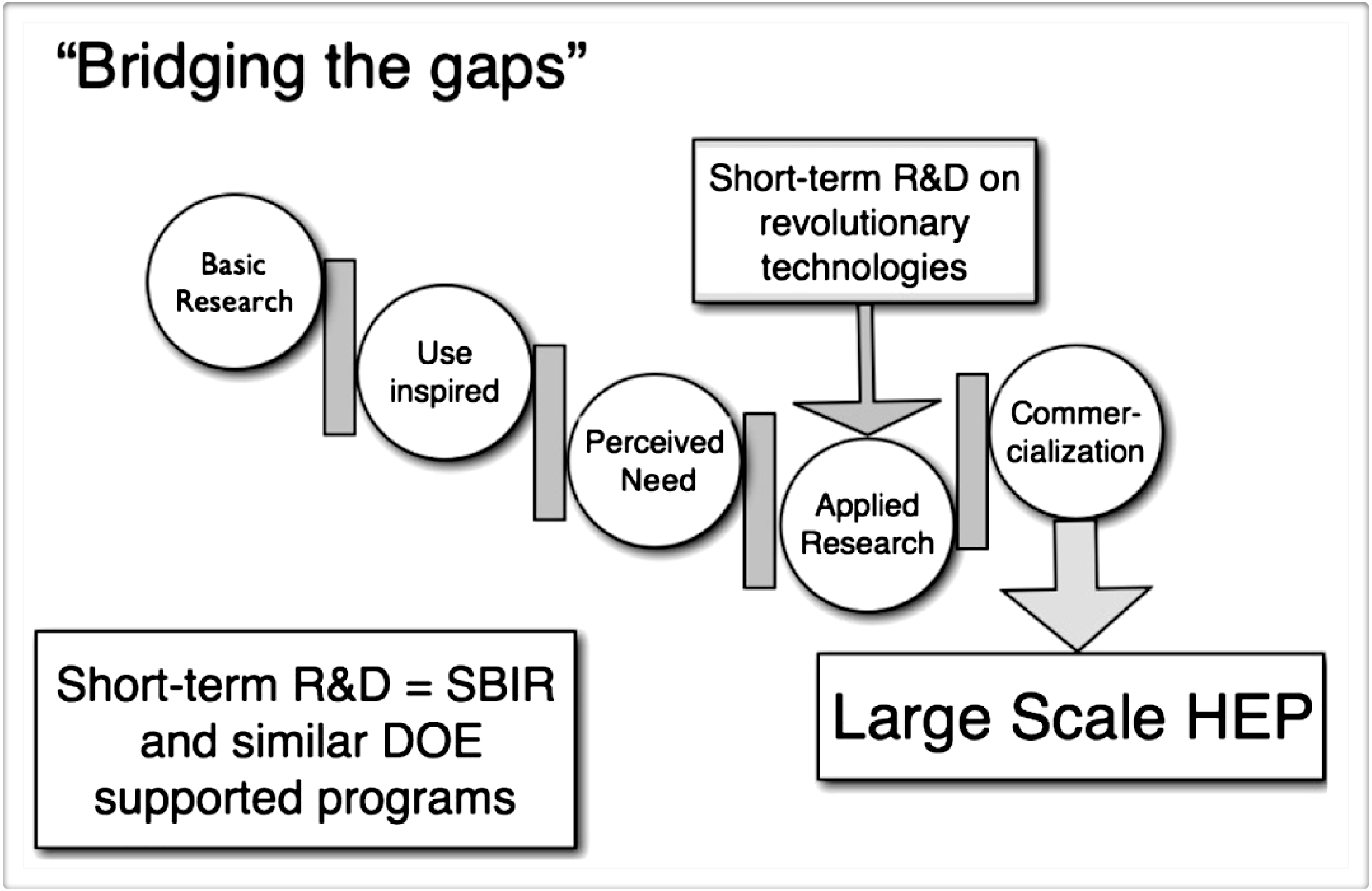
Textured-powder samples before and after non-melt heat treatment (870C, 24h)
grains row x5 in a-b plane

The role of Magnet Programs:
Example of the LHC Luminosity upgrade

B. Strauss & S. St Laurent, TAS 2011

B. Strauss &
S. St Laurent,
TAS 2011

The role of Magnet Programs:
Example of the LHC Luminosity upgrade



The role of Magnet Programs:
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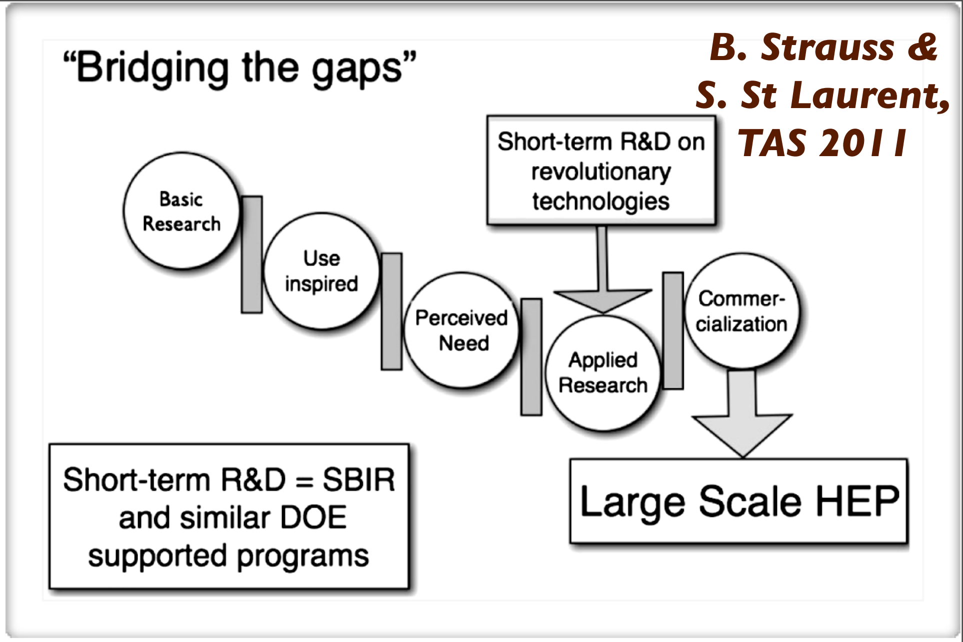

The role of Magnet Programs:
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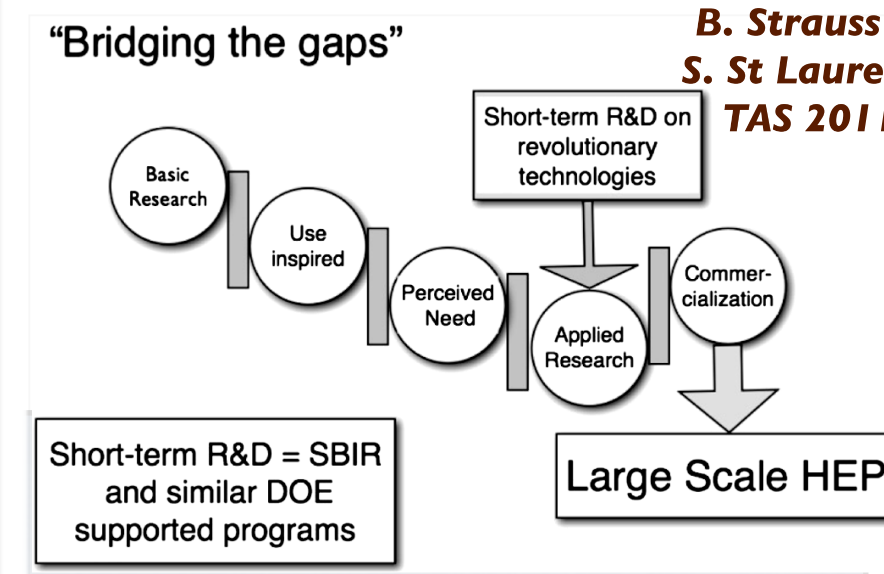


B. Strauss & S. St Laurent, TAS 2011

Base program primary focus: basic research

R&D - focus on understanding physics

Technology R&D - focus on developing engineering solutions and processes

Systems engineering - focus on robust procedures, QC/QA Manufacturability

***High-Luminosity LHC*:**

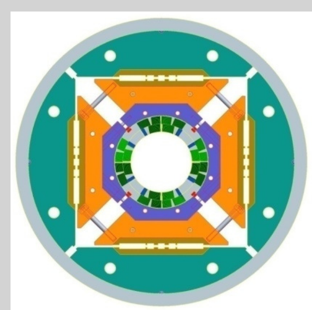
- First priority in HEP (HEPAP, P5)
- Requested US support **~250 M$**
- Nb_3Sn is the baseline technology

***High-Energy LHC*:**

- Malta workshop in Nov. 2010
- "Yellow book" report released
- Rapidly gaining visibility/priority

LARP focus; technology readiness

Magnet Systems

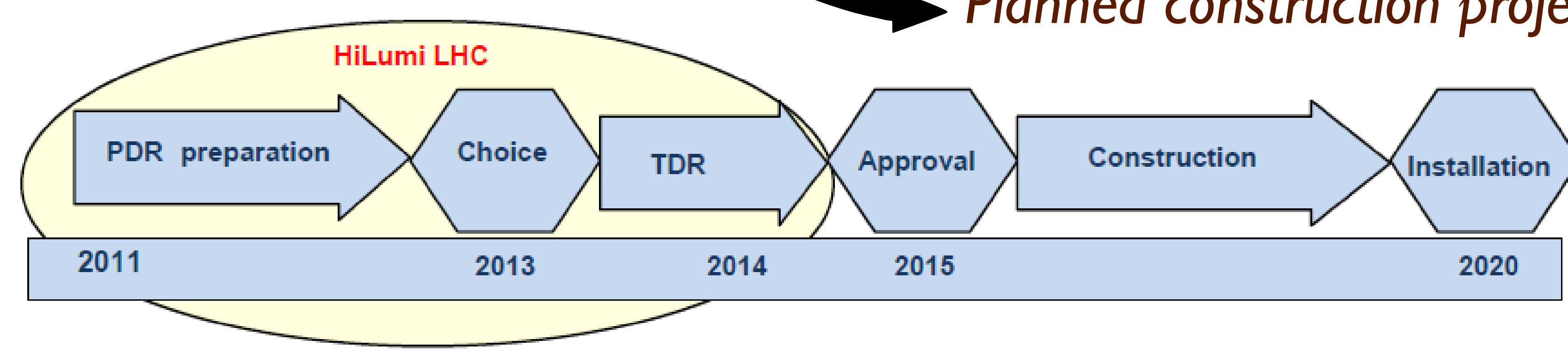


Materials
- Strand characterization
- Cable development

Model Quadrupoles
- Technology Quadrupoles
- High-field Quadrupoles

Long Quadrupoles
- Coil fabrication
- Structure and assembly
- Instrumentation and Test

Planned construction project



Conclusions

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- The US Magnet Programs serve as...
  - ➡ ***Incubators*** of new accelerator magnet concepts
  - ➡ ***Developers*** of technologies for accelerator magnets
  - ➡ ***Centers*** of magnet design, fabrication, and testing expertise

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- The US Magnet Programs serve as...
  - ➡ ***Incubators*** of new accelerator magnet concepts
  - ➡ ***Developers*** of technologies for accelerator magnets
  - ➡ ***Centers*** of magnet design, fabrication, and testing expertise
- The programs are characterized by...
  - ➡ vertically-integrated capability and expertise
    - ✓ Full range: conductor, cable, coil design and fab, magnet, test
  - ➡ Broad and significant infrastructure
    - ✓ R&D capabilities, fabrication, testing,...
  - ➡ Expertise, and history, in start-to-finish accelerator magnets
    - ✓ Concept development
    - ✓ Concept maturation / technology readiness
    - ✓ Construction project / implementation