Challenges of Constructing 30-100 TeV Hadron Colliders

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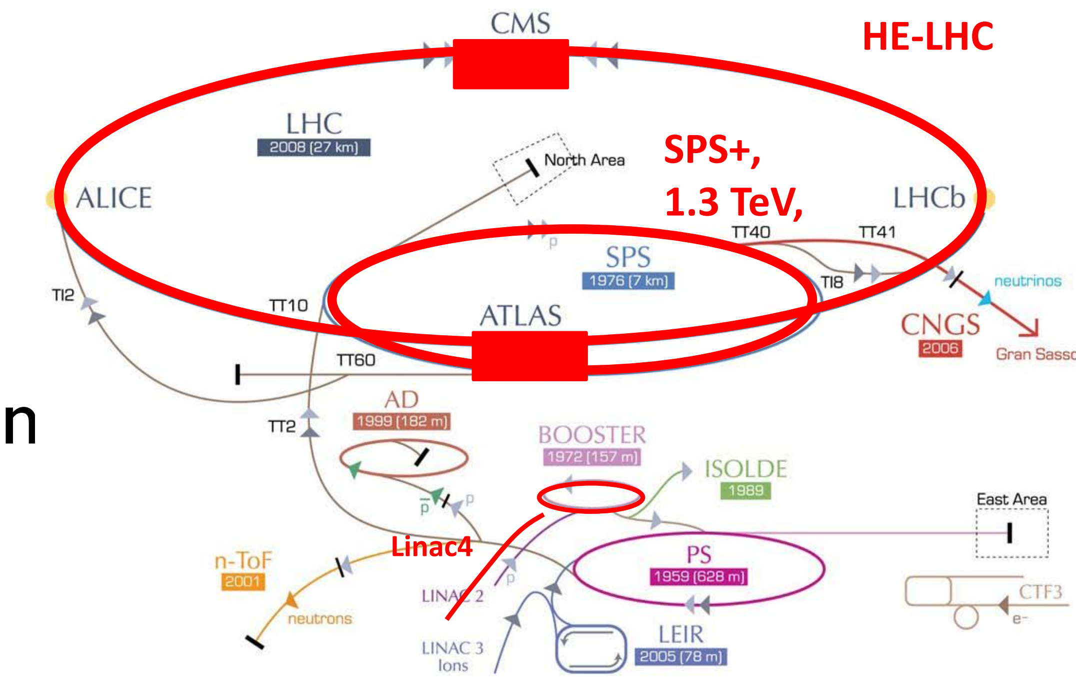
With liberal use of materials from colleagues
(in particular from Snowmass pre-meeting slides and from whitepapers)

Overview

- A large Hadron collider entails...
  - ➡ A high intensity proton source,
  - ➡ Fast-cycling magnets for the injection chain
  - ➡ New magnets - probably high-field
  - ➡ A new tunnel
    - ✓ Exception: HE-LHC could reach E_{cm}=33TeV with 20T dipoles...

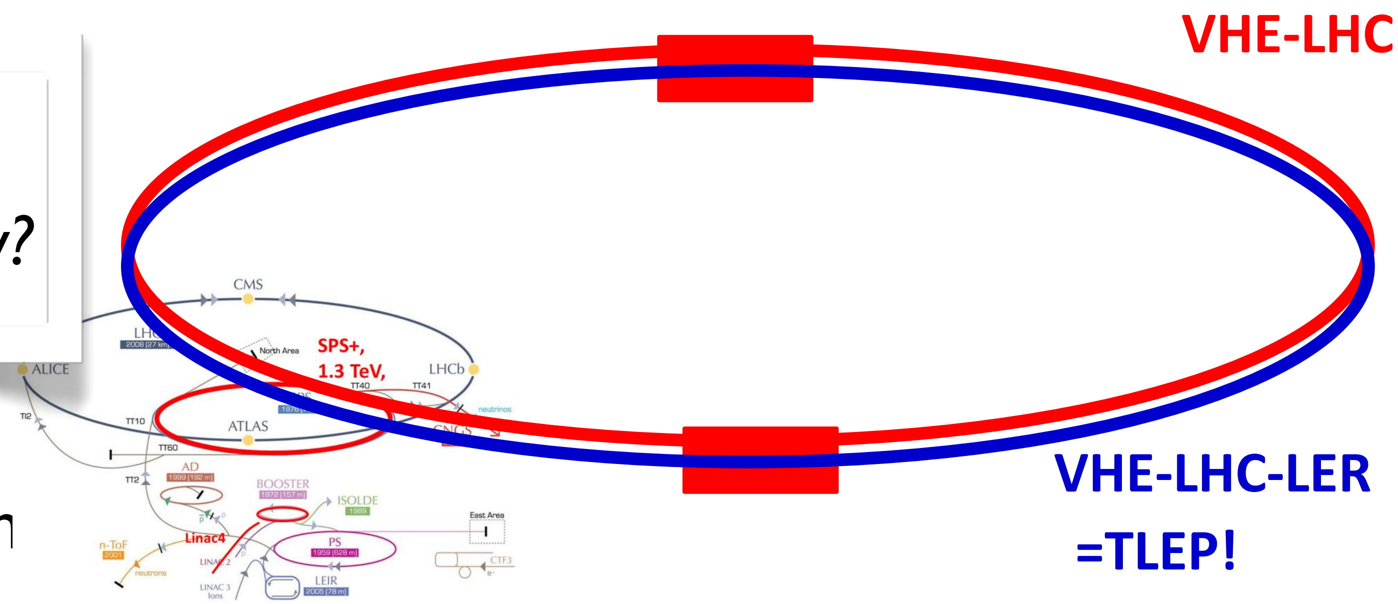


- **Dominant cost drivers: Magnets and tunnel**

Photon stops?

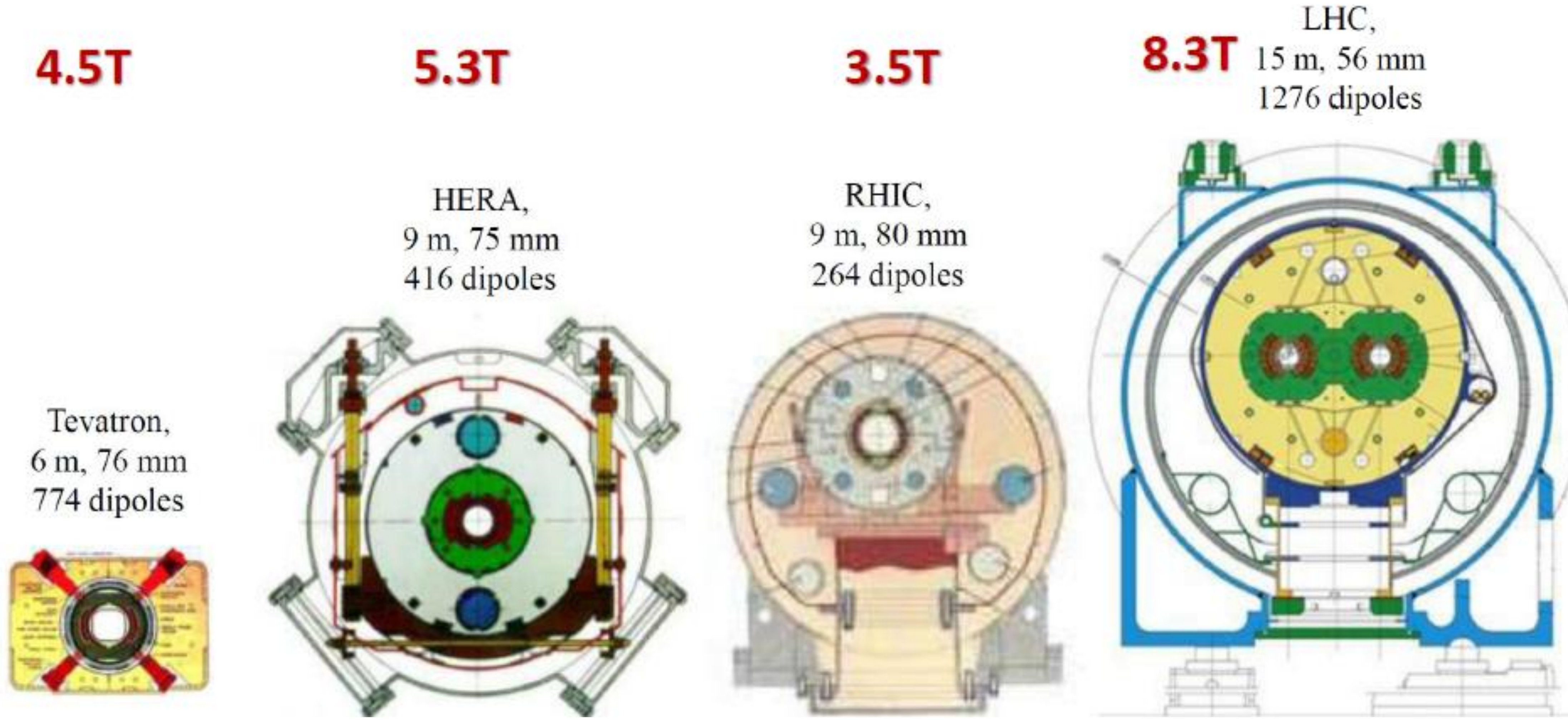
New vac technology?

- Other issues:
  - ➡ Synchrotron radiation
    - ✓ cooling, cooling power, vacuun



(Lucio Rossi)

Magnet structure (usually) grows with field

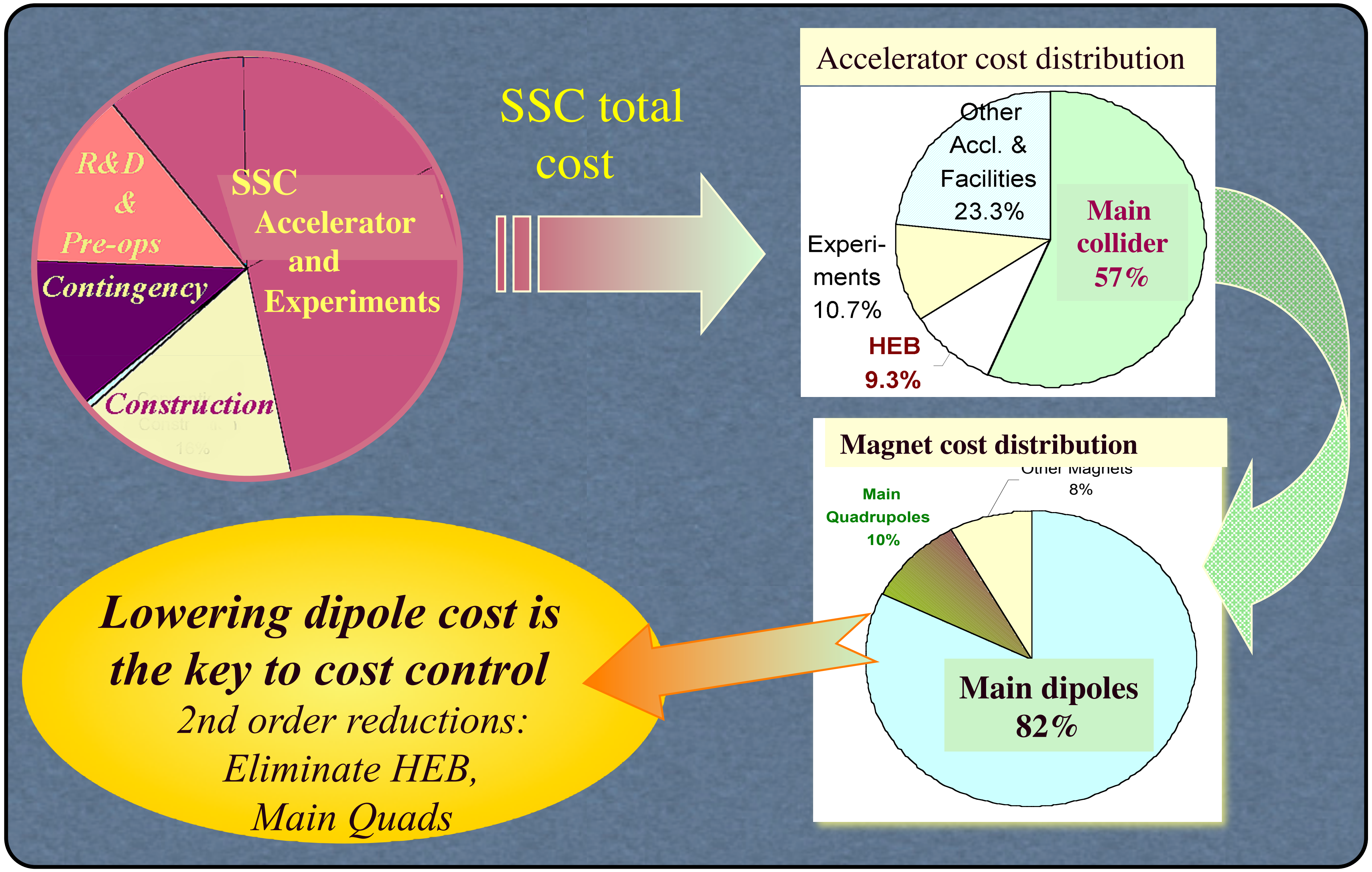


Shiltsev/Zlobin

$$E_{mag} \propto r_0^2 B^2$$

$$\Delta E = \frac{4\pi}{3}\frac{e^2\gamma^4}{R}$$

Magnets dictate collider cost



Barletta

CERN cost estimates*:

$\$_{magnets}/\$_{tot}$

LHC: 57%

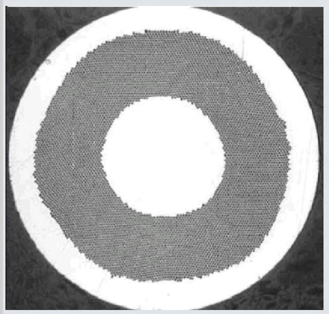
HE-LHC:

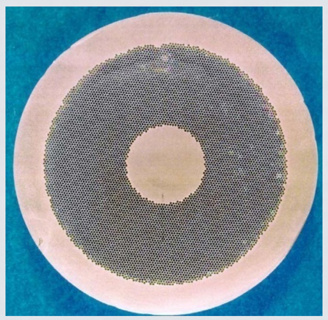
- 70% (26TeV; Nb_3Sn)
- 77% (33TeV; HTS)

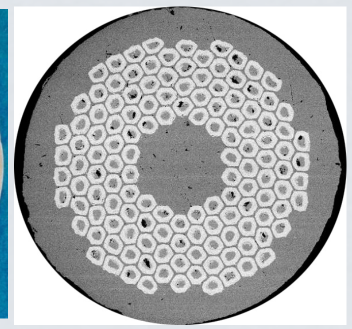
**L. Rossi, "TOE" talk*

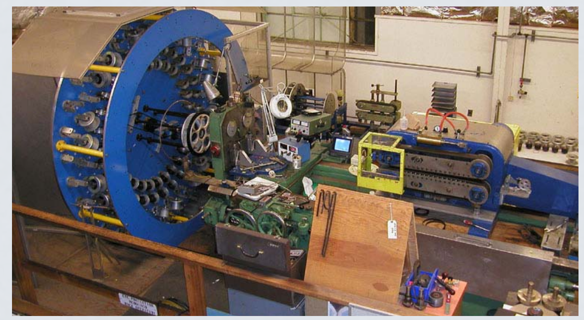
Technology development

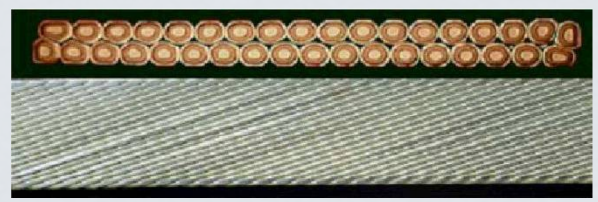
From conductor to magnets

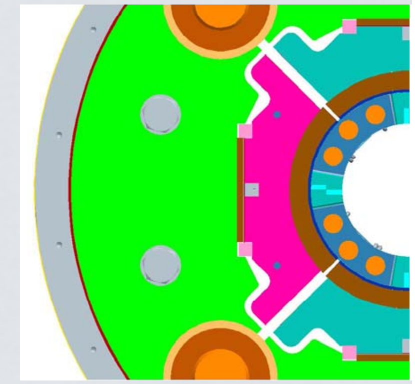

NbTi LHC wire (A. Devred, [1])

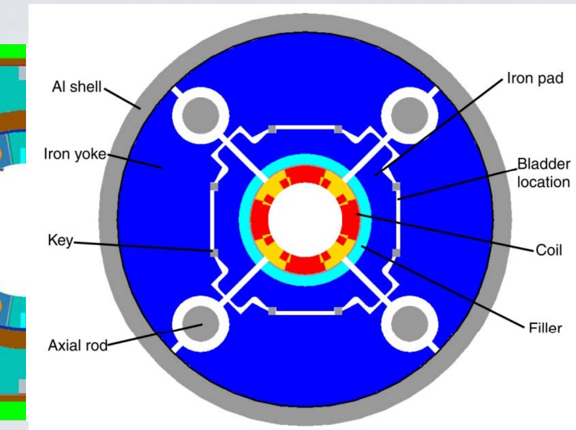

NbTi SSC wire (A. Devred, [1])

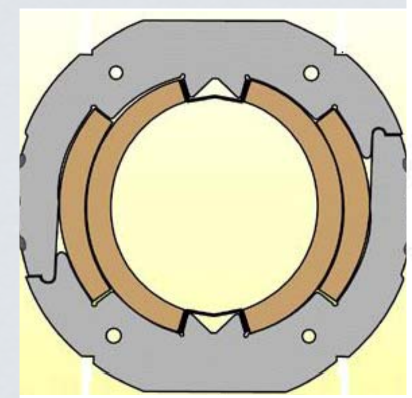

OST 169-stack

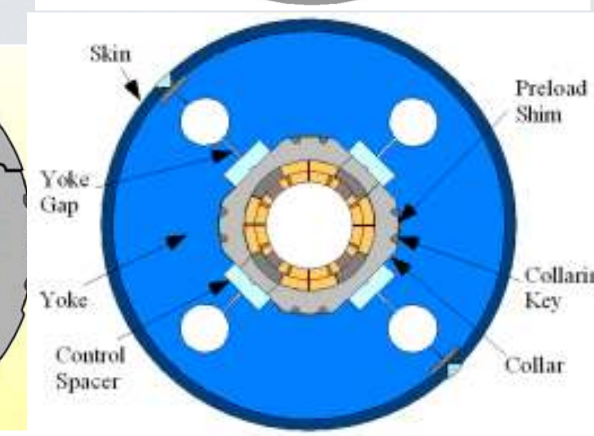












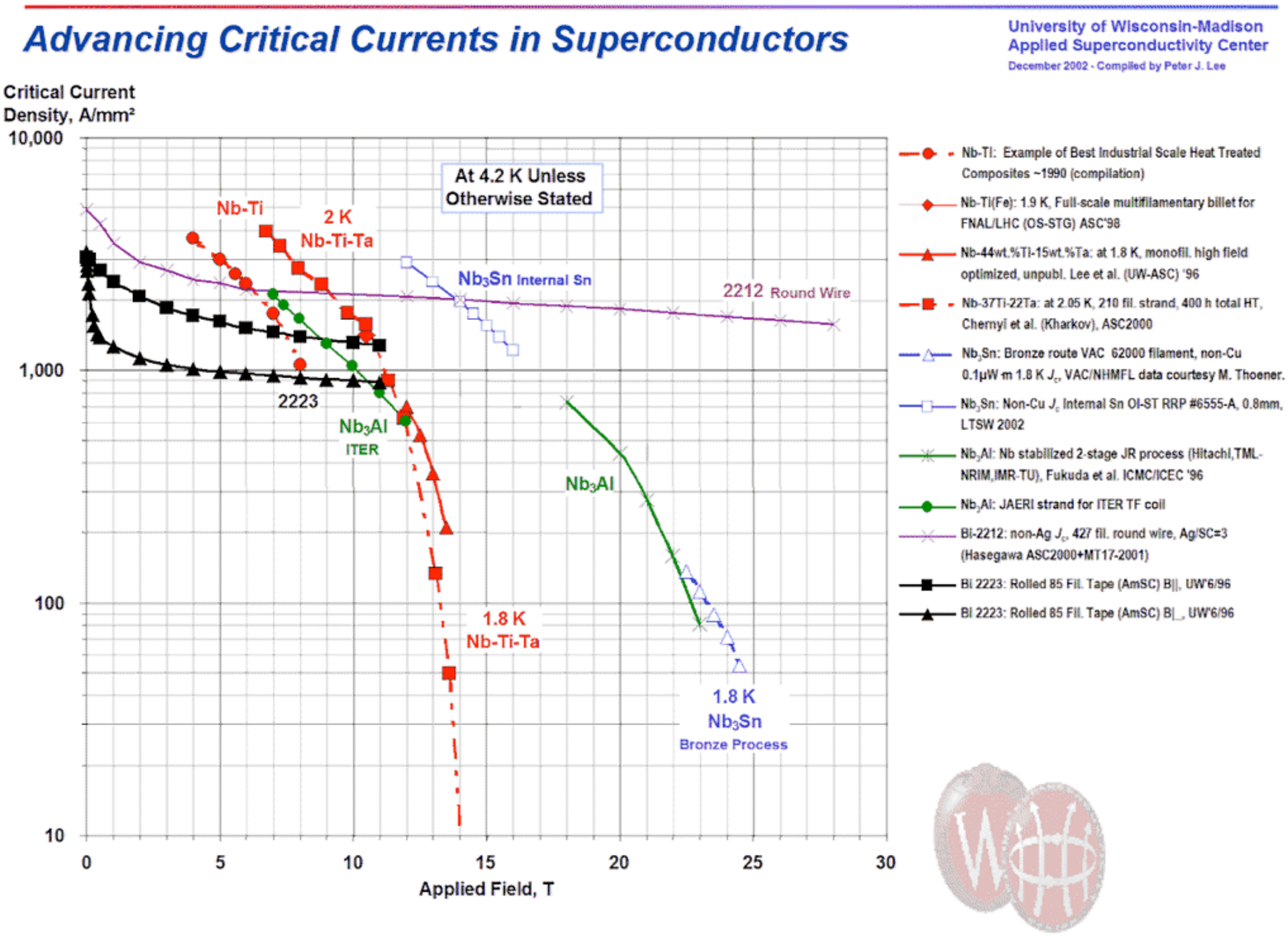
Conductor ⇨ Cable ⇨ Magnetic design ⇨ Structure design

Coil fabrication ⇨ Magnet assembly ⇨ Magnet test

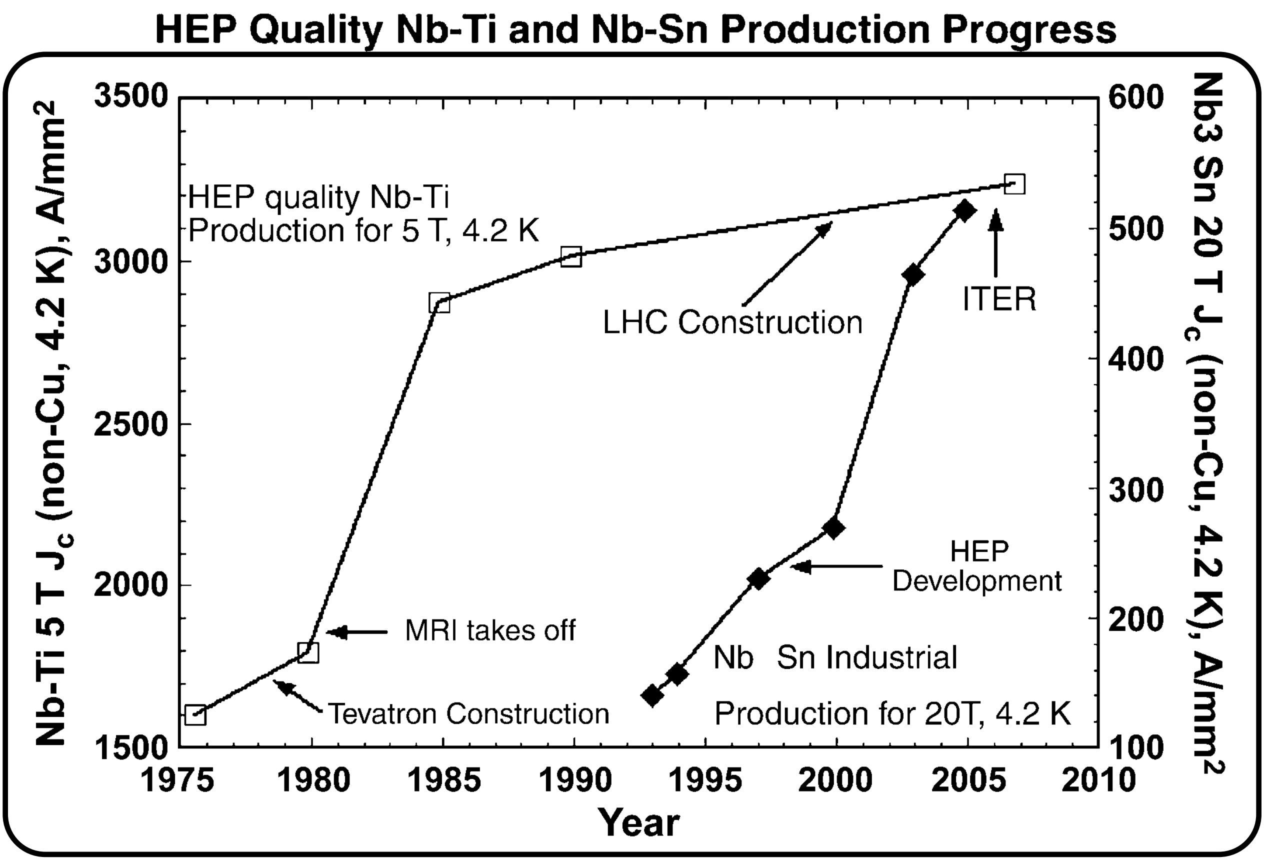
Evolution of HEP rings...

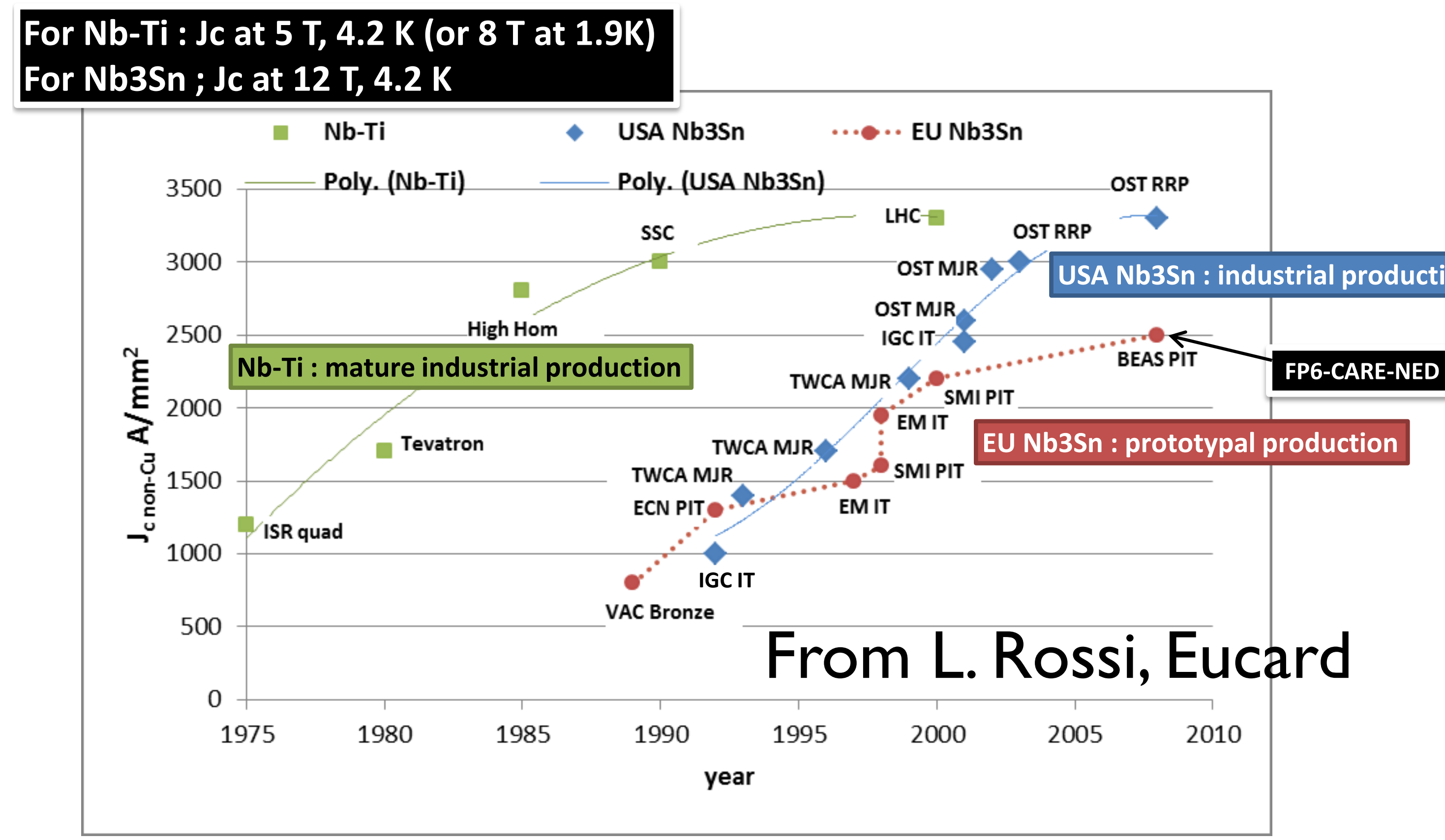
The next BIG machine!

Conductor options



HEP and Superconductor Industry





- Conductor architecture important for dipoles:
  - ➡ Need small filaments to reduce persistent currents
  - ➡ Need high Cu RRR for stability
  - ➡ Need high-quality cables to...
    - ✓ Provide for high currents (low inductance)
    - ✓ Minimize conductor degradation

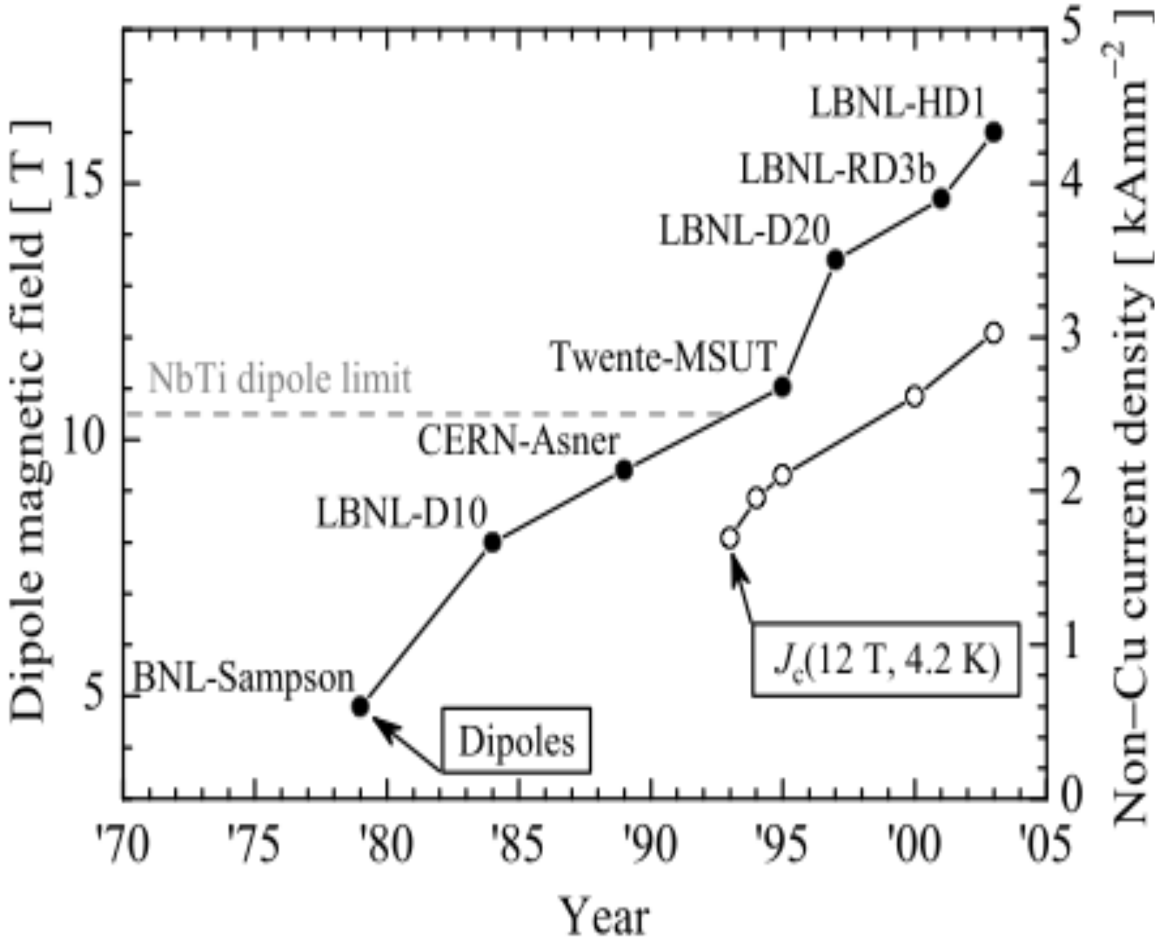
Nb₃Sn nearly ready

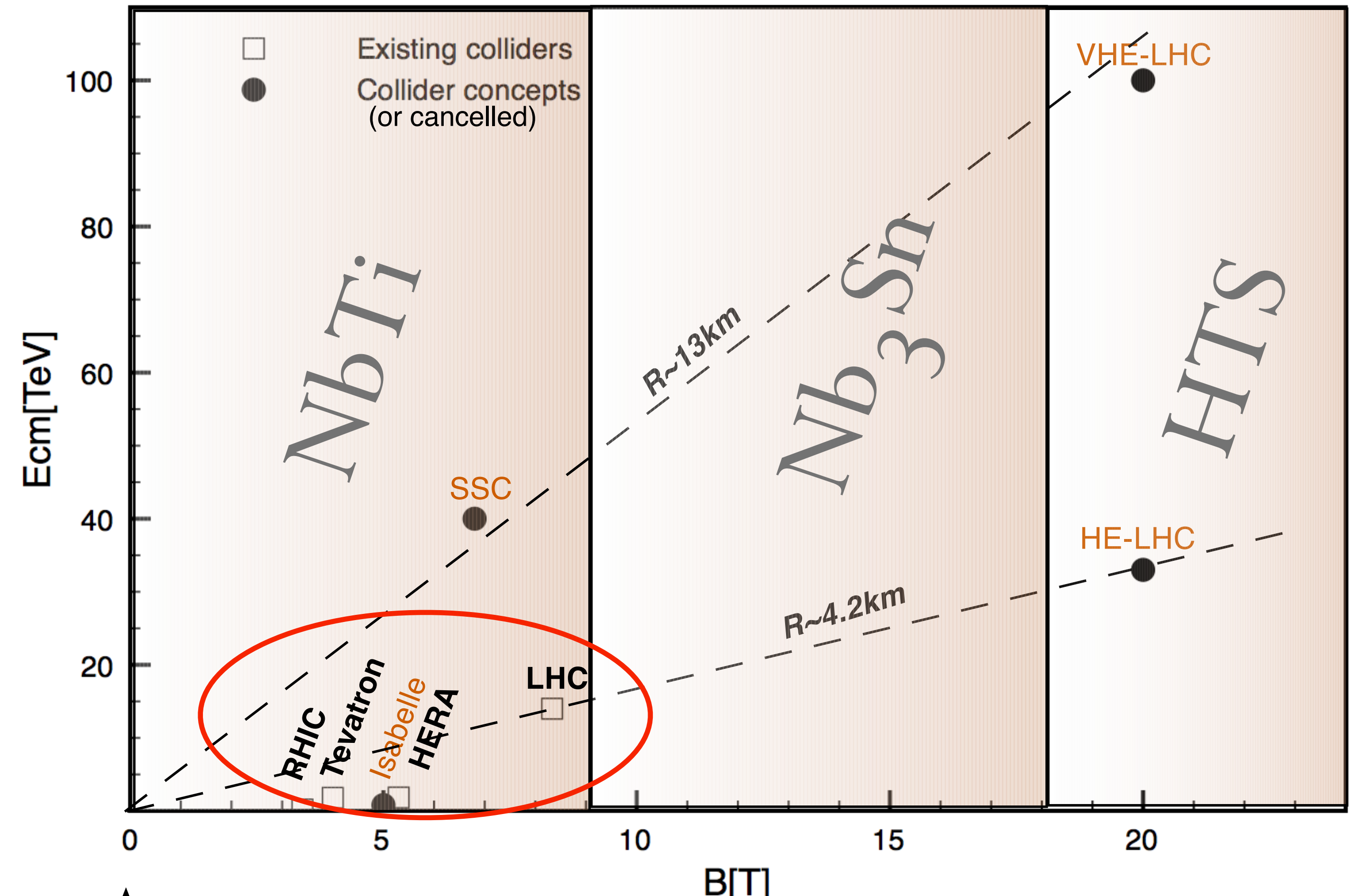
need smaller filaments

HTS has a long way to go

need conductor R&D

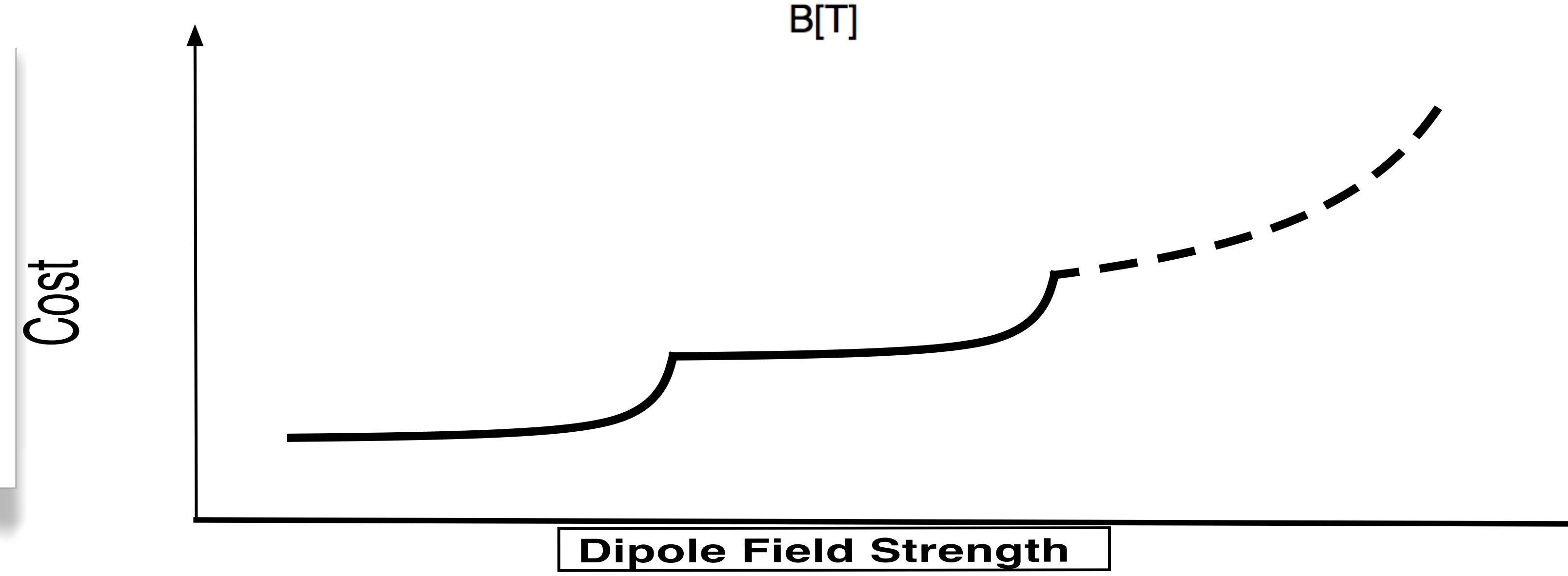
Magnets and conductors





DOE-HEP GAD Support for Materials Conductor Development Program (CDP)

- Very successful in guiding industrial development of high-Jc Nb3Sn



GAD Program Role in R&D and transition to project

R&D - focus on understanding physics, developing concepts

Base program primary focus: basic research, incubator: support critical for innovation

High Luminosity LHC

VLHC

LHC Energy Upgrade

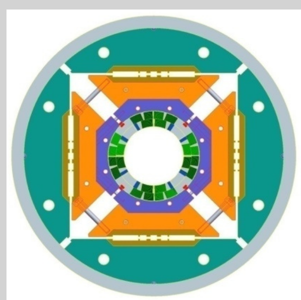
Muon Collider

...

LARP focus: technology readiness

Technology Development - focus on engineering solutions and processes

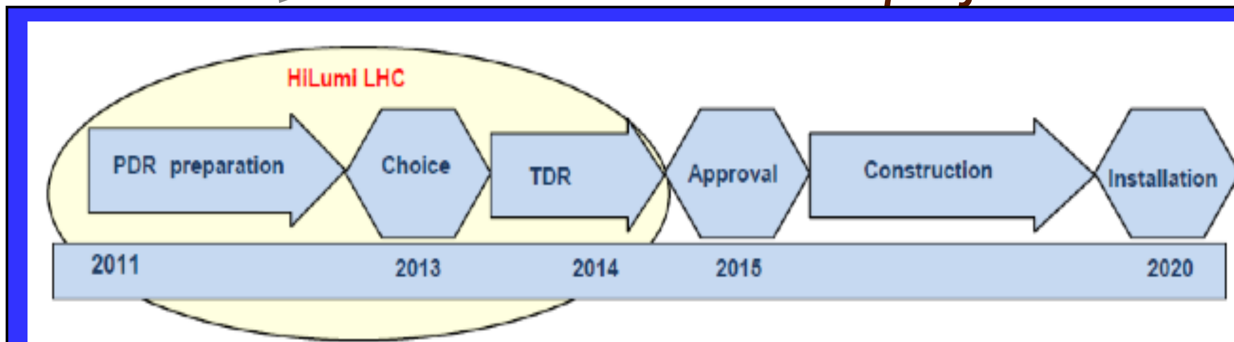
Magnet Systems



Materials	• Strand characterization • Cable development
Model Quadrupoles	• Technology Quadrupoles • High-field Quadrupoles
Long Quadrupoles	• Coil fabrication • Structure and assembly • Instrumentation and Test

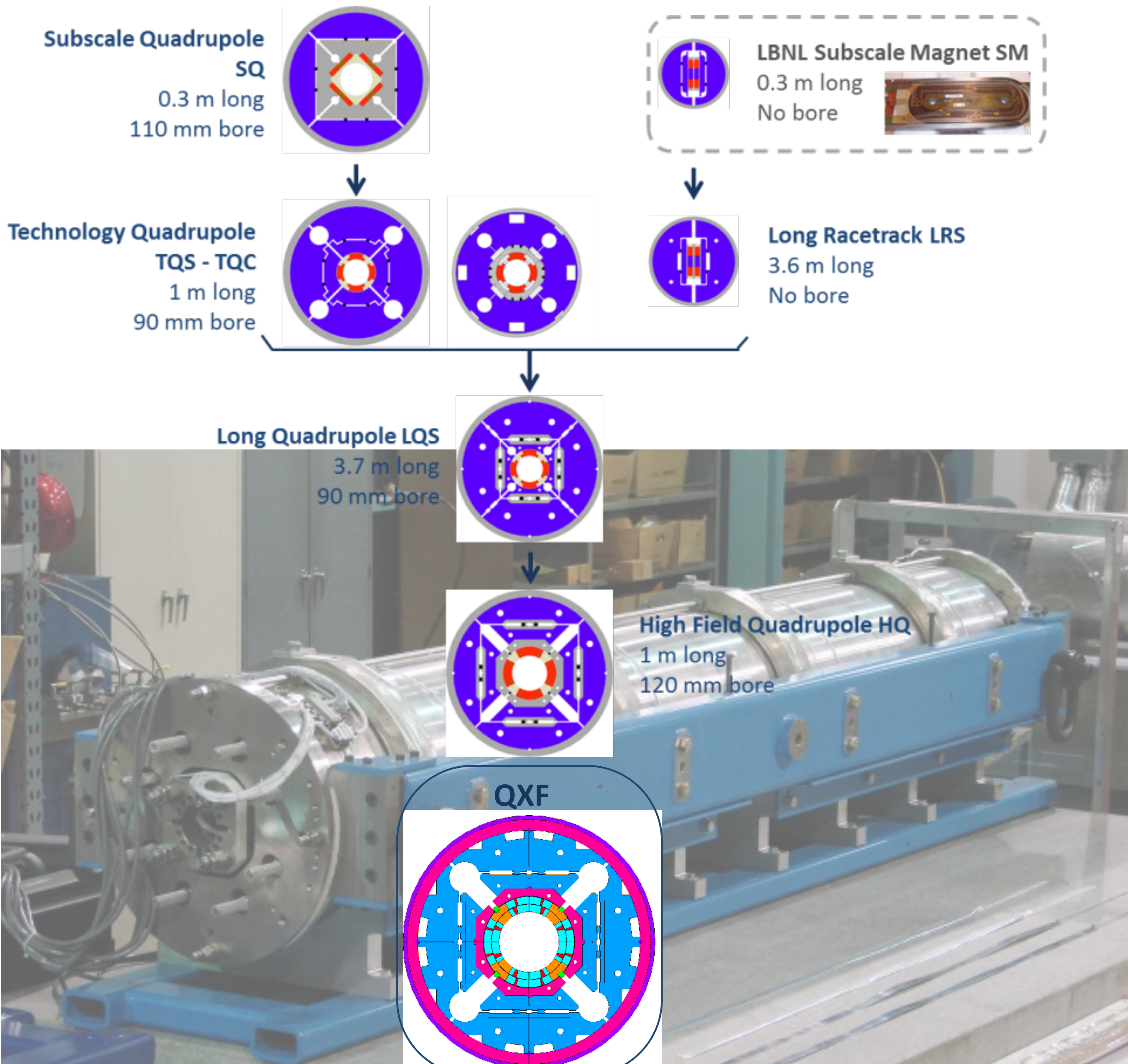
Planned construction project

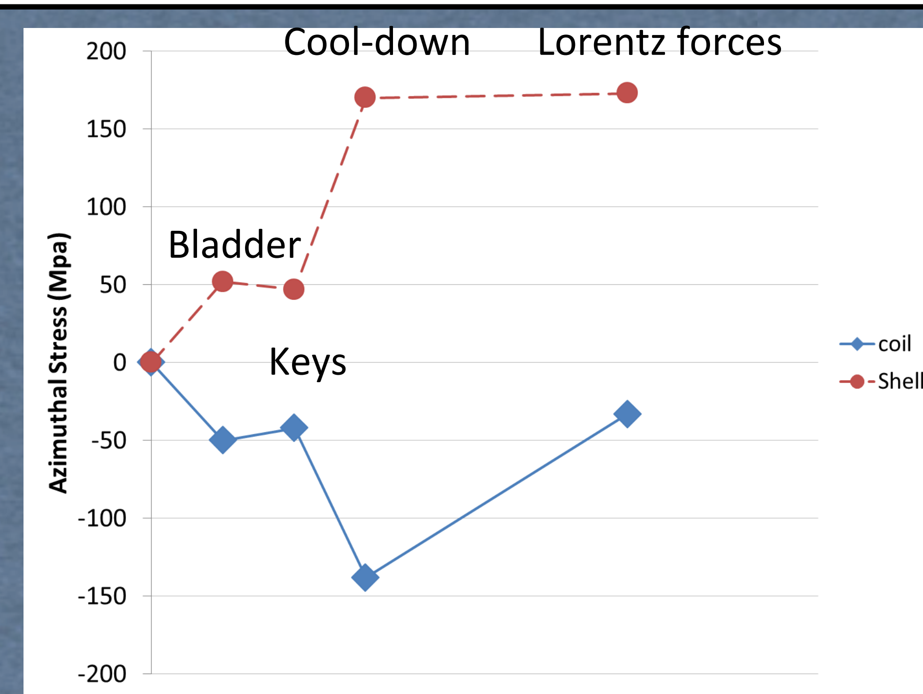
Systems engineering - focus on robust procedures, QC/QA Manufacturability

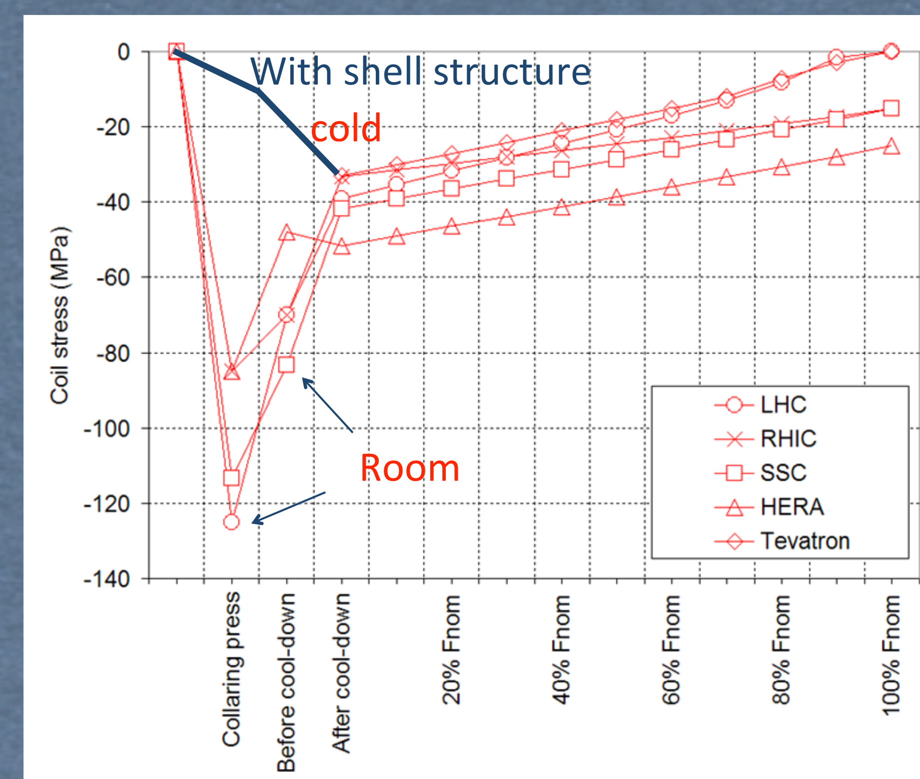


Distinction between R&D (Concept incubator) and Technology Readiness (Project)

LARP: Technology Readiness





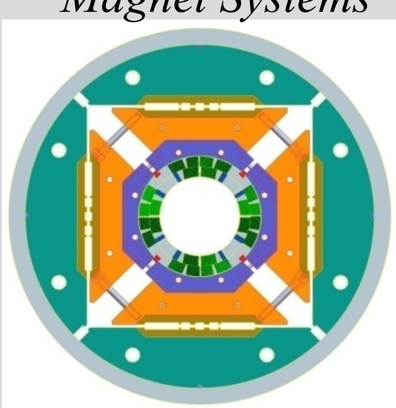


Collaring process- Courtesy of Paolo

Many issues to address...

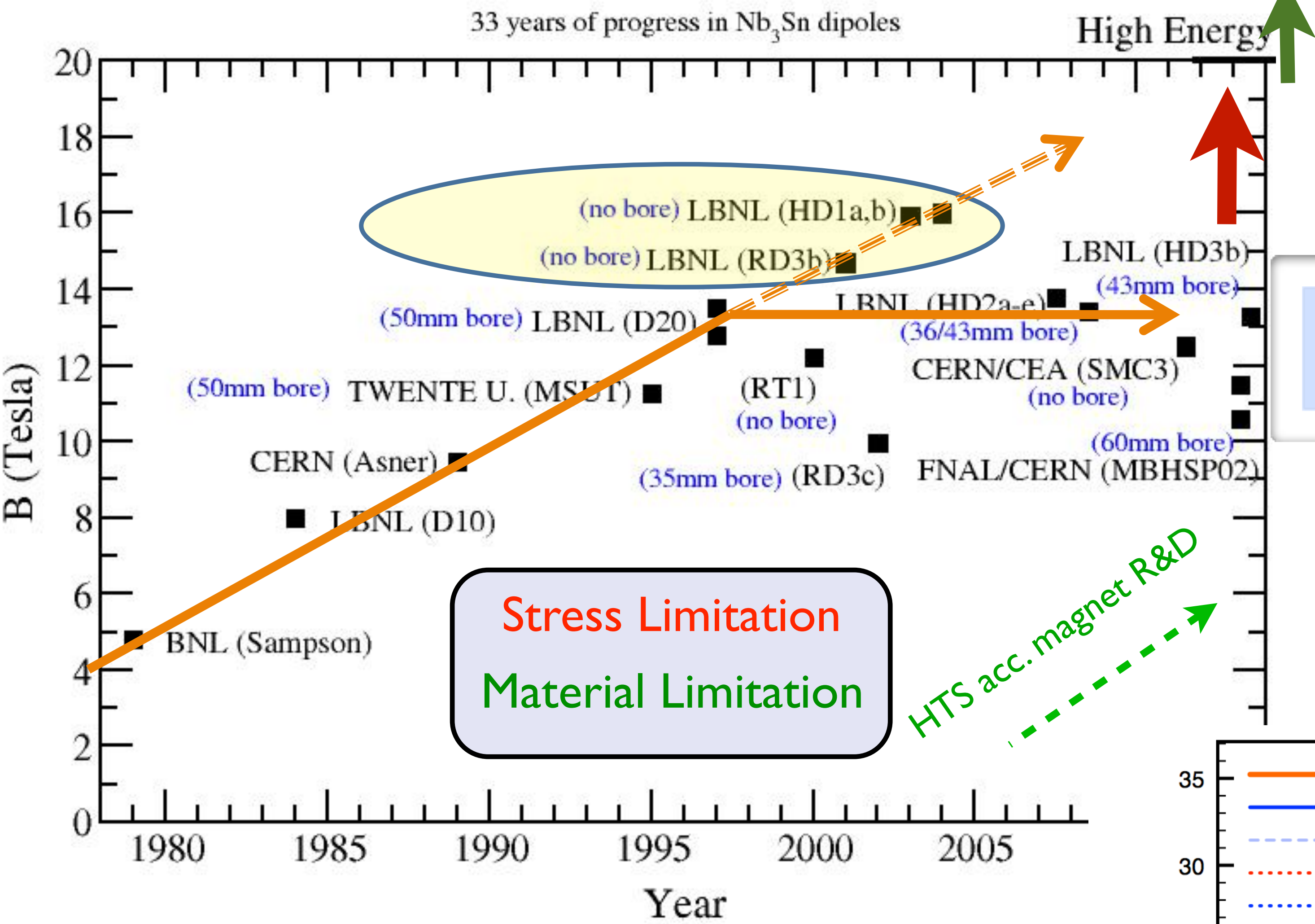
- Conductor: baseline ok; improvements being investigated
  - ➡ need to demonstrate industrial scale-up
- Cable: new design for QXF (due to 120=>150 change)
  - ➡ Possible issues of degradation, stability
  - ➡ Incorporation of core (first tested on HQ)
- Magnet reproducibility
- Magnet production QA

Magnet Systems

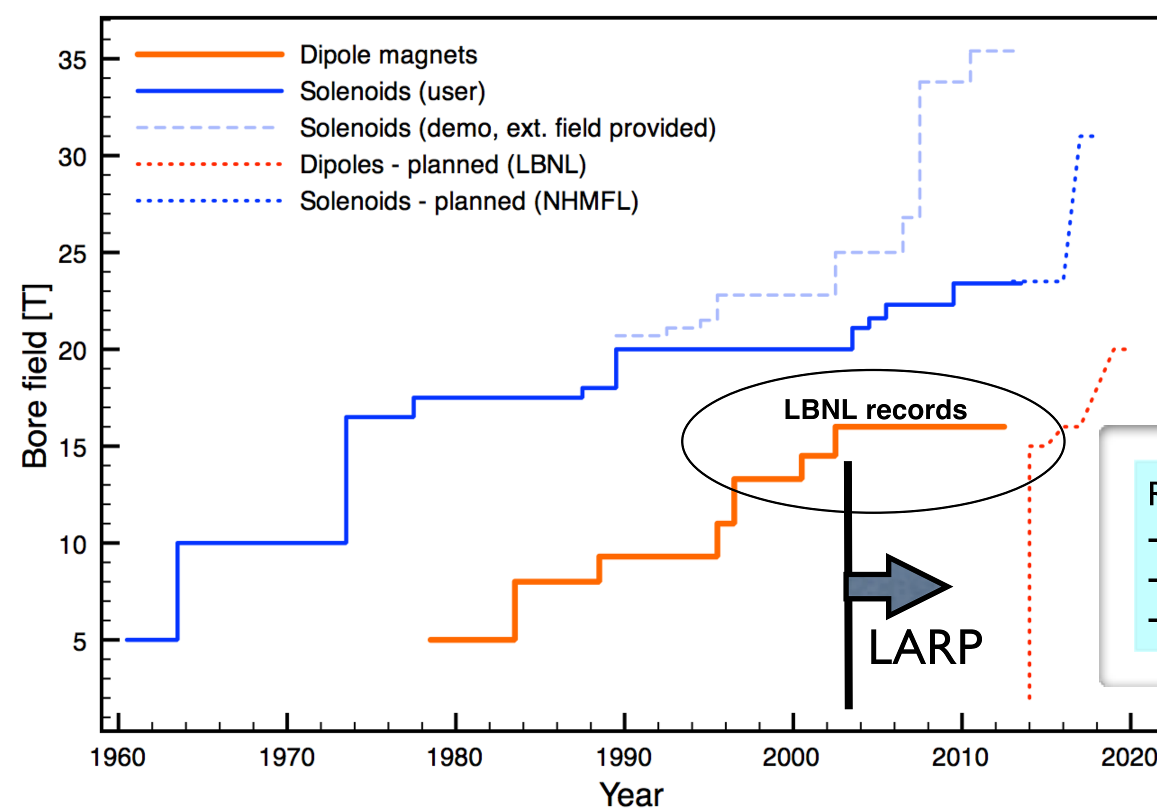


Materials	• Strand characterization • Cable development
Model Quadrupoles	• Technology Quadrupoles • High-field Quadrupoles
Long Quadrupoles	• Coil and structure
Prototype Quadrupoles	• Performance demo

High-Field Accelerator Magnets



- •Technology configurations have strengths and weaknesses
- •Bore affects performance of racetrack design concepts

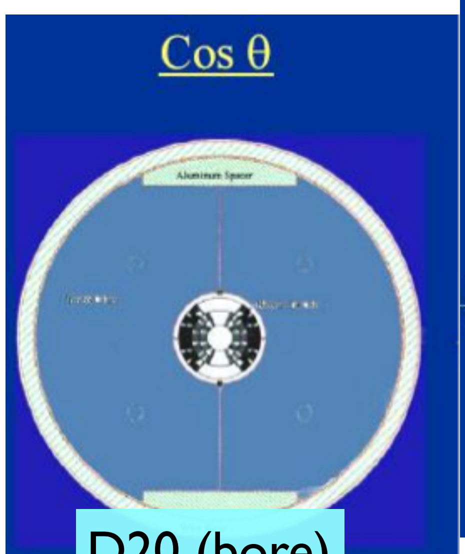


Record...
- Cos(θ): D20
- Common coil: RD3b
- Block: HD1-3

For dipoles>~15T

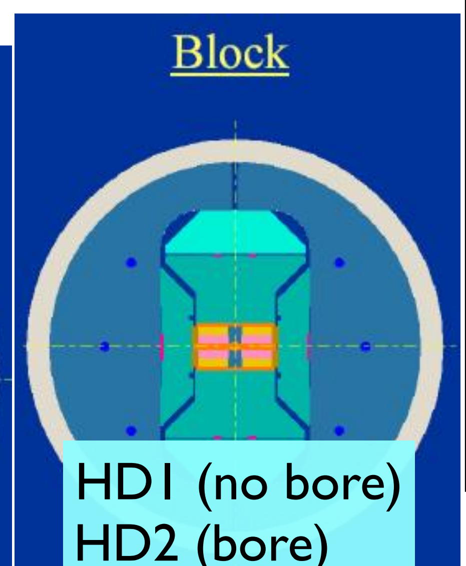
Need a new paradigm to address stresses

Need to consider efficiency (grading), scalability



D20 (bore)

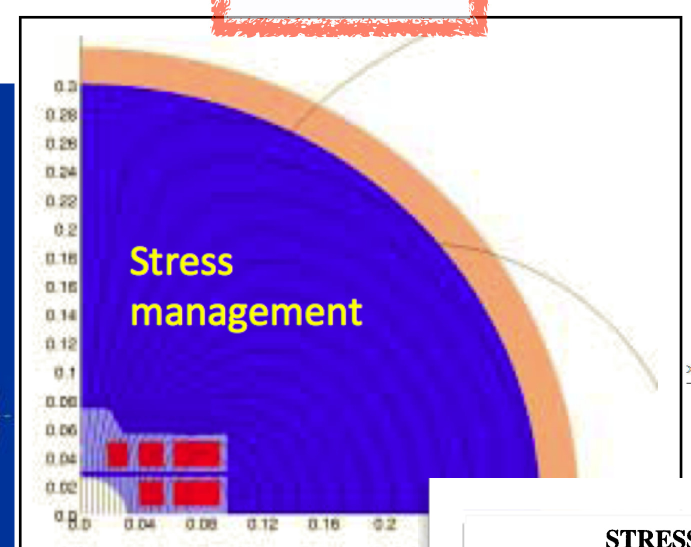
RD3a,b (no bore)
RD3c (bore)



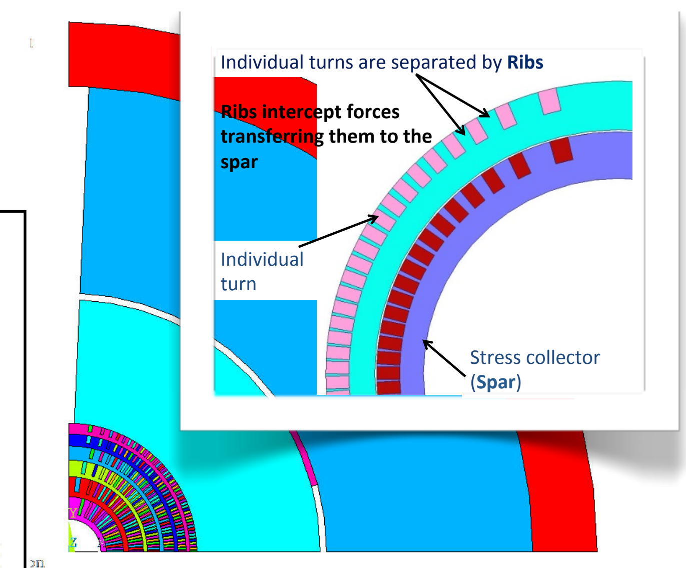
HD1 (no bore)
HD2 (bore)

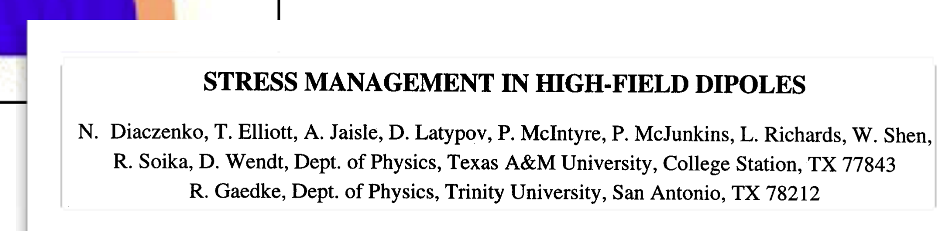
HD3 (bore)

TAMU



CCT




STRESS MANAGEMENT IN HIGH-FIELD DIPOLES

N. Diaczenko, T. Elliott, A. Jaisle, D. Latypov, P. McIntyre, P. McJunkins, L. Richards, W. Shen, R. Soika, D. Wendt, Dept. of Physics, Texas A&M University, College Station, TX 77843
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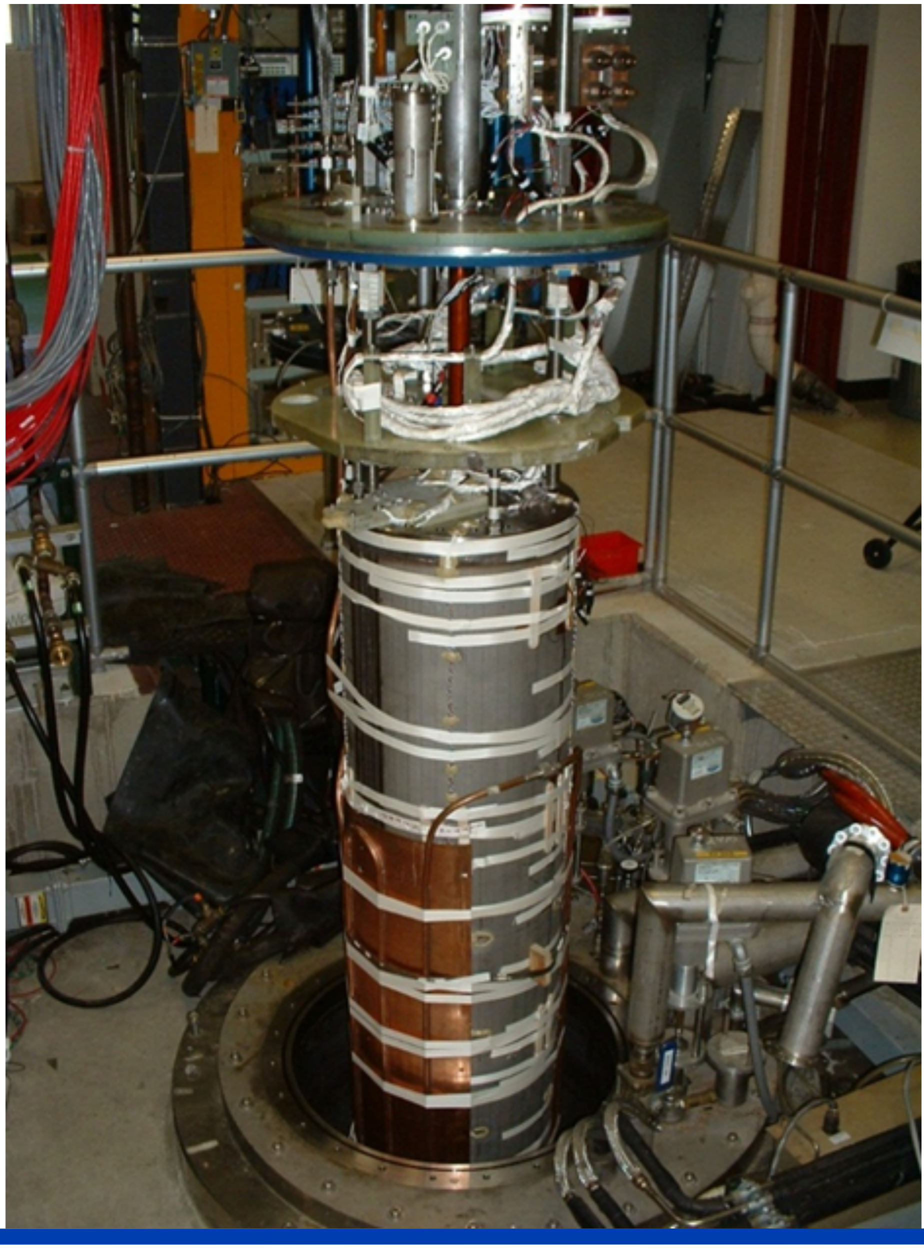
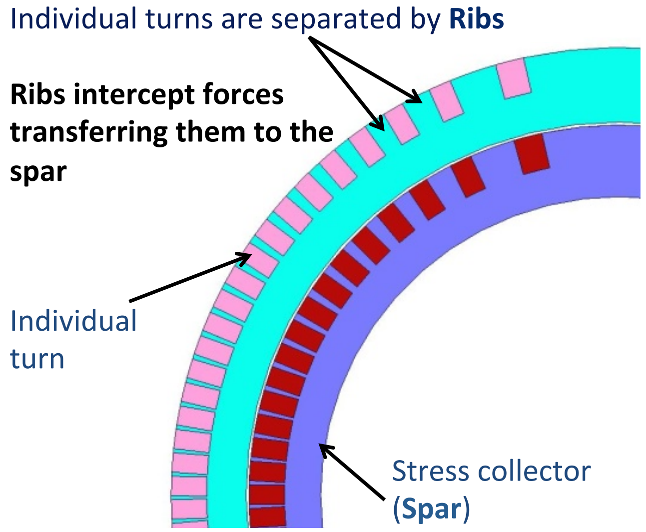
How do GAD (R&D) programs serve the HEP community?

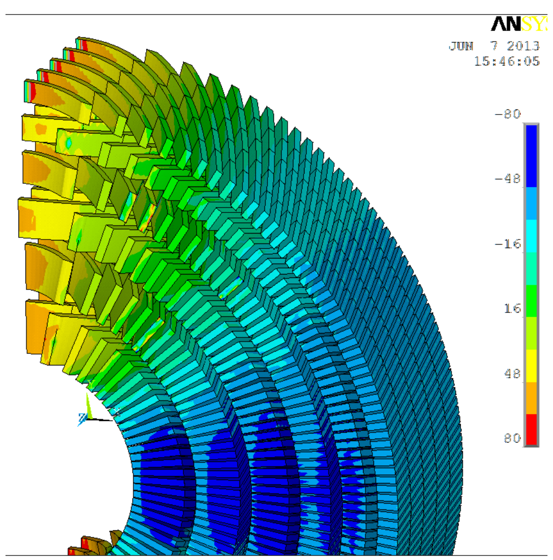
- R&D paves the way for HEP magnets
  - ➡ Shell-structure set the stage for LARP
  - ➡ GAD program 13-16T dipoles set the stage for ~15T HE-LHC baseline concepts (see recent L. Rossi presentations)
  - ➡ ongoing dipole development
    - ✓ FNAL - 11T sets stage for first Nb_3Sn dipole in accelerator
    - ✓ LBNL - new structure paradigm sets the stage for
      - Accelerator-magnet-quality 16T dipoles
      - More cost-effective designs: leverage grading, simpler assembly
      - Possible 20+T designs optimally leveraging HTS for VHe-LHC, muon collider

FNAL 11T

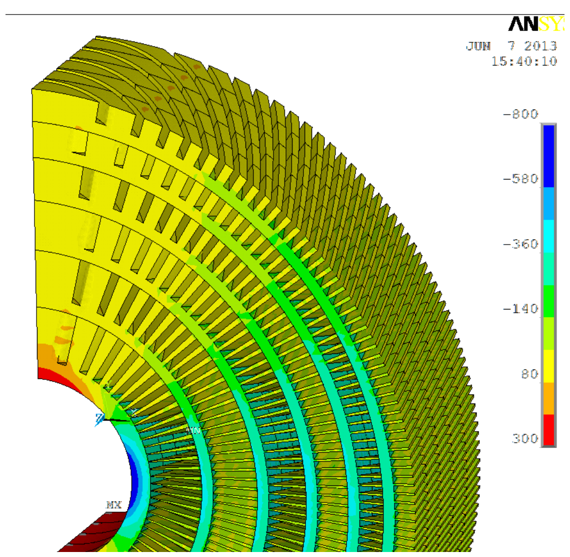




Coil stresses



Structure stresses



Looking forward

- Dipole fields of ~15T are within reach...
  - ➡ But need a focused ~10 year "LARP-like" readiness program
- Dipole fields >15T need R&D
  - ➡ Need to investigate new concepts/paradigms to break through the stress-barrier - prerequisite for real application of HTS
- Strategy:
  - ➡ Maintain R&D until clear project on the horizon
  - ➡ Then initiate focused Readiness program before project start, e.g. HE-LHC or another Hadron collider

Summary

- Dominant technology challenge is in magnets
  - ➡ GAD programs and LARP provide balanced approach to
    - ✓ innovate for higher fields, cost effective magnets
    - ✓ develop technology for project readiness
  - ➡ Materials R&D translates into magnet performance

US has leadership role in these areas

- Synchrotron radiation issue
  - ➡ Vacuum issues are significant - need development+experiments