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Nb_3Sn Technology for High Field Accelerator Magnets

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Outline

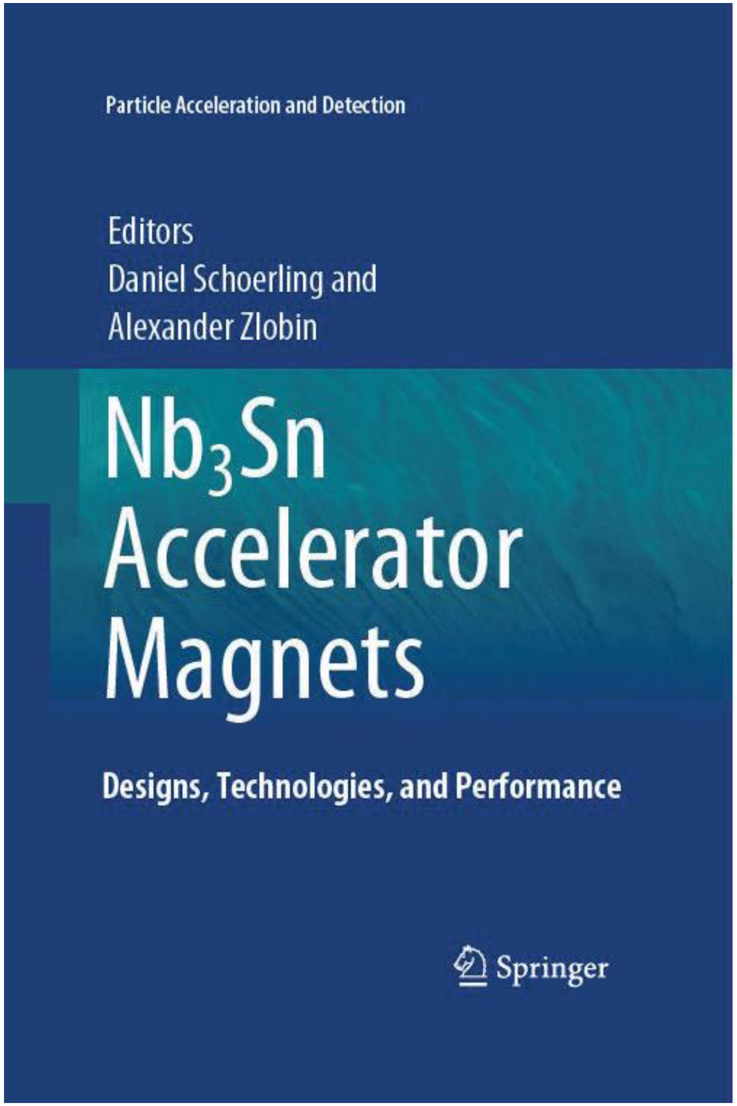
JLEIC plan include stage 2 with magnetic field to be increased from 6.16 T by a factor of 2 to 12.3 T. It requires using Nb_3Sn accelerator magnets.

In this talk I will discuss

- Present status of Nb_3Sn accelerator magnet technology
  - Nb_3Sn wires and cables
  - Coil design and technology
  - Mechanical structures
  - Quench performance
  - Field quality
  - Performance reproducibility
  - Technology scale up
  - Application in accelerators
- R&D directions
- Remarks on Nb_3Sn magnets for JLEIC
- Summary

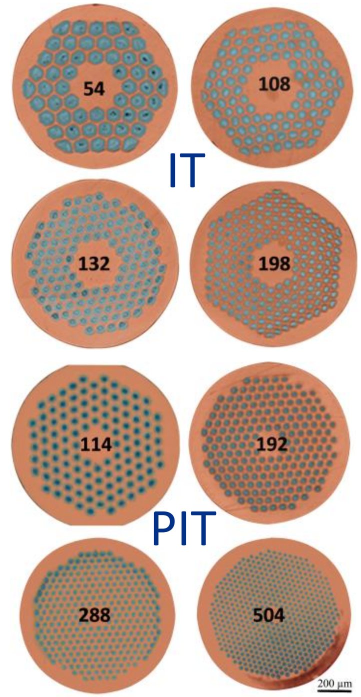
Introduction

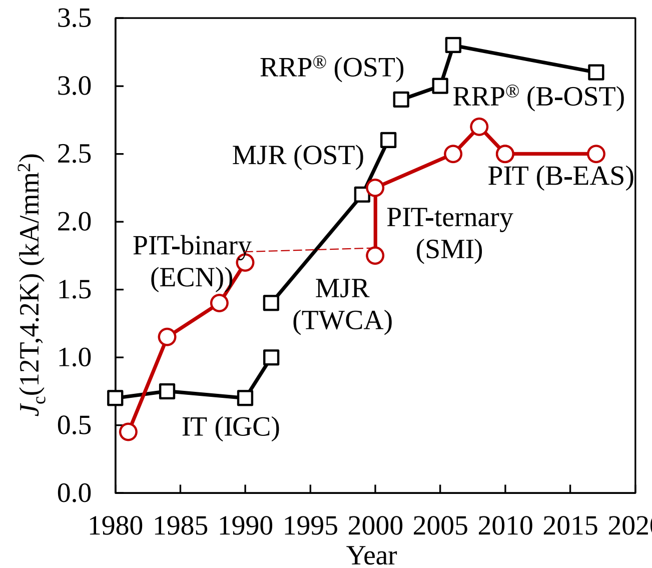
- Nb_3Sn accelerator magnet history
  - 1967 – the first Nb_3Sn quadrupole model
  - 1989 – the first 9.5 T dipole model
  - 2018 – record dipole field of 14.6 T (FRESCA2, CERN)
- The book
  - ~450 pages on Nb_3Sn accelerator magnet (dipoles) designs, technologies and performance
  - written by world experts in Nb_3Sn accelerator magnet technologies
  - open access
  - available in June 2019

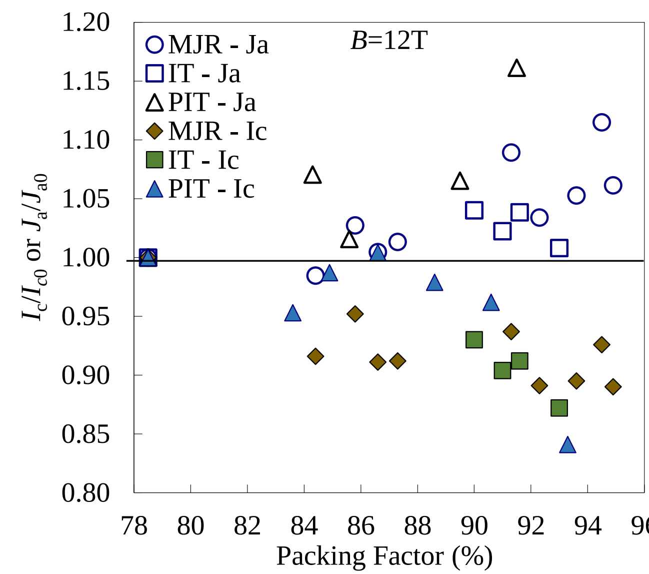


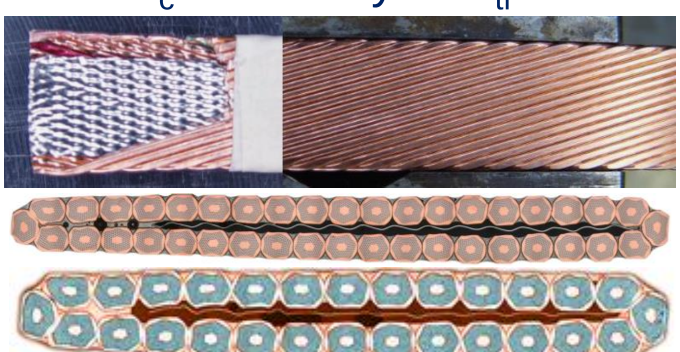
Nb_3Sn wires and cables

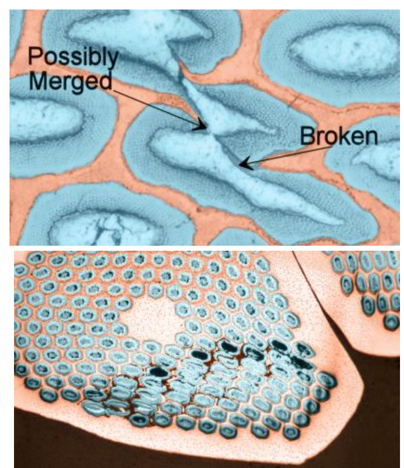
- Nb_3Sn composite wire
  - Bronze, IT and PIT
  - Cu matrix, RRR~250
  - OD=0.5-1.0 mm
  - D_{eff}~23-85 mcm
  - SC after HT reaction, brittle, flux jumps, large M
- Rutherford cable
  - N<60, PF~85-87%
  - SS core
  - I_c degradation <5%
  - I_c sensitivity to P_{tr}











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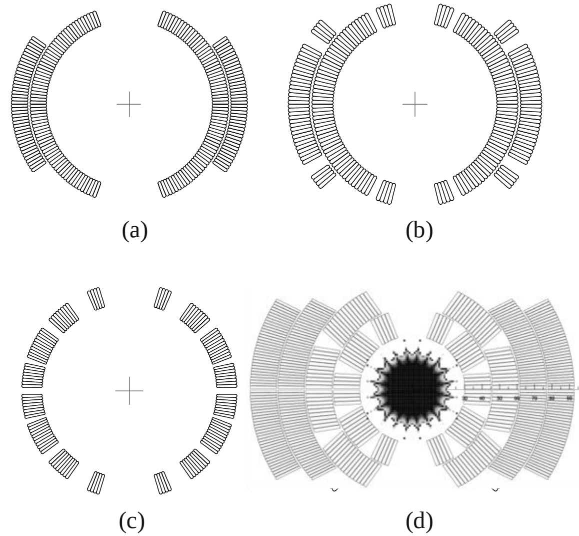
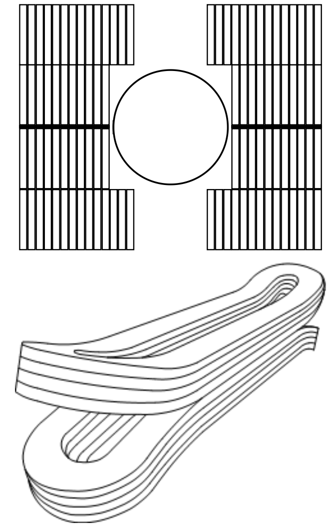
Nb_3Sn coil technology

- R&W vs W&R
- Metallic components
- HT insulation

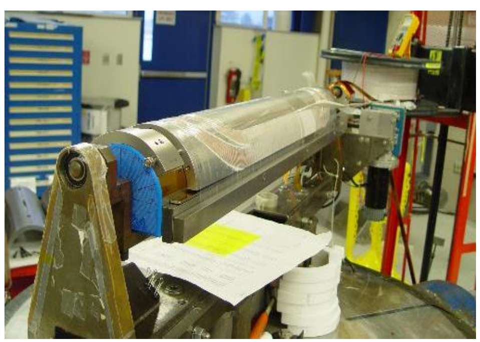
Cos-theta coils



Block-type coil



Coil winding and curing, Ceramic binder



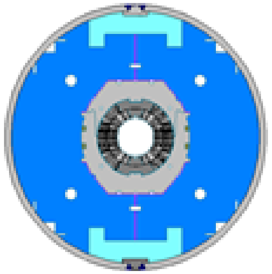
Coil reaction, radial and azimuthal expansion gaps

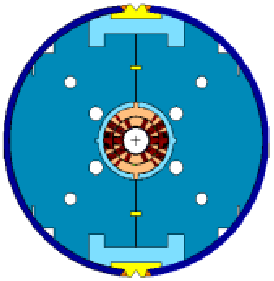
Coil epoxy impregnation to reinforce brittle insulation

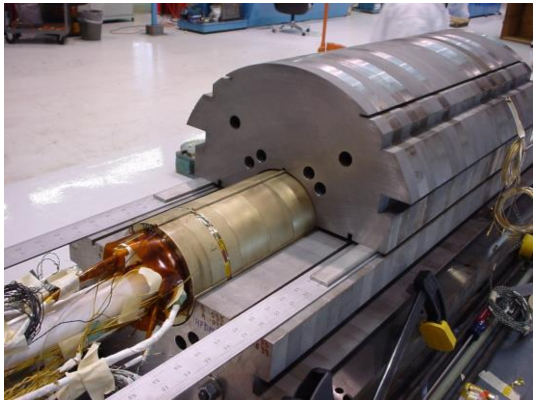
Coil transportation at different stage, storage, etc.

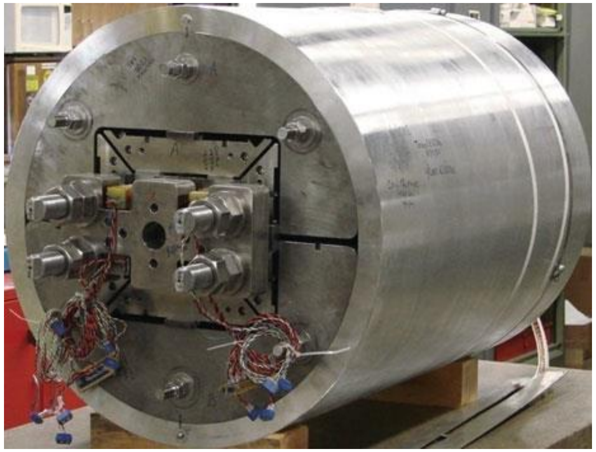
Mechanical structure

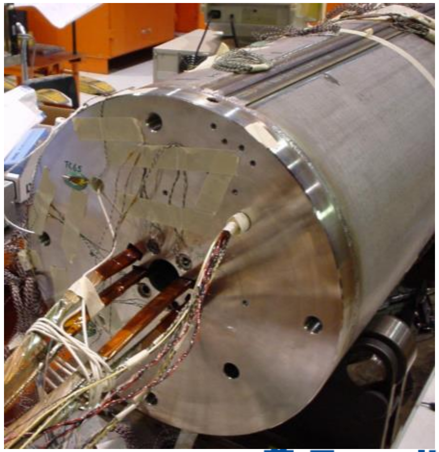
- Coil-collar-yoke-skin
- Coil-yoke-Al clamp-skin
- Coil-yoke-Al shell-skin



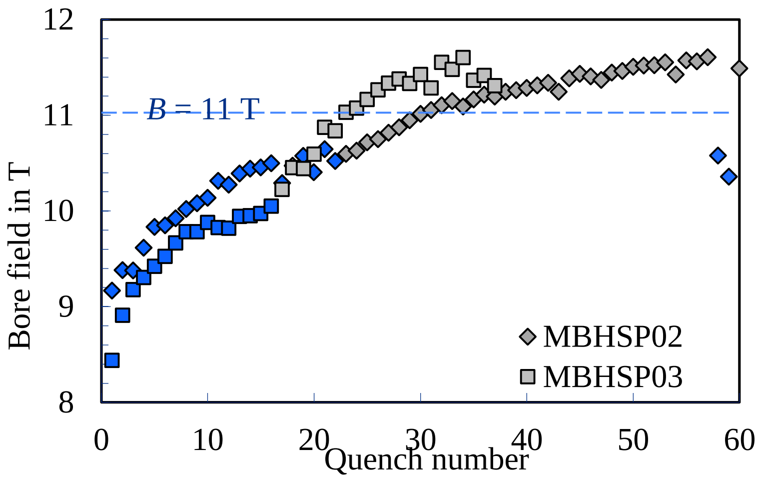


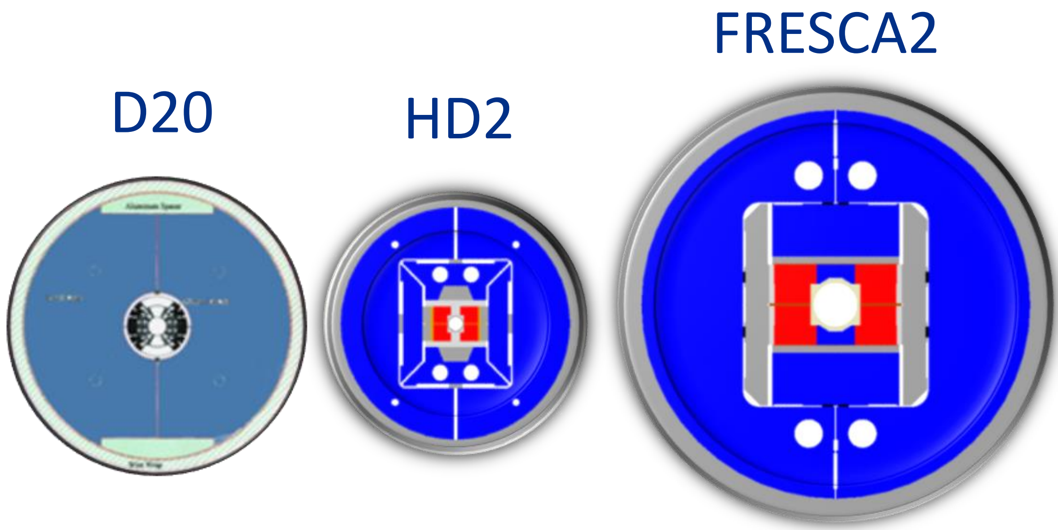






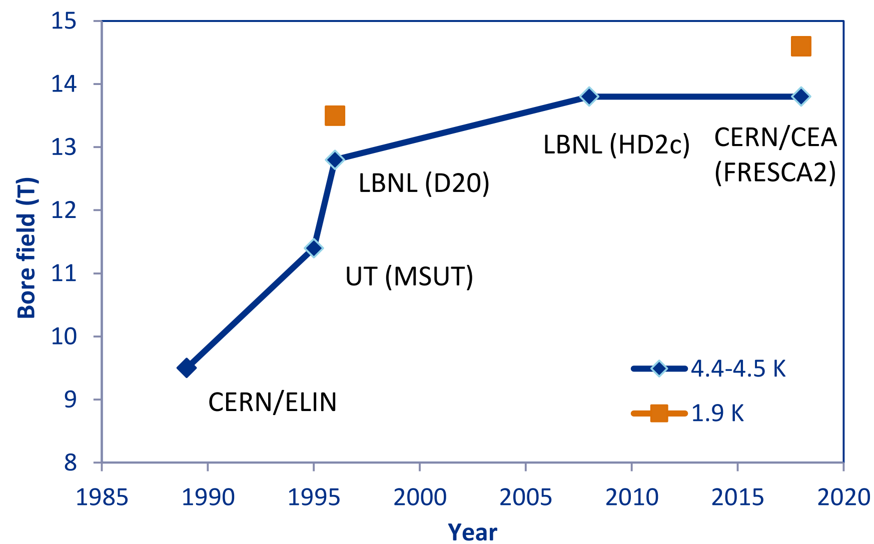
Nb_3Sn magnet quench performance



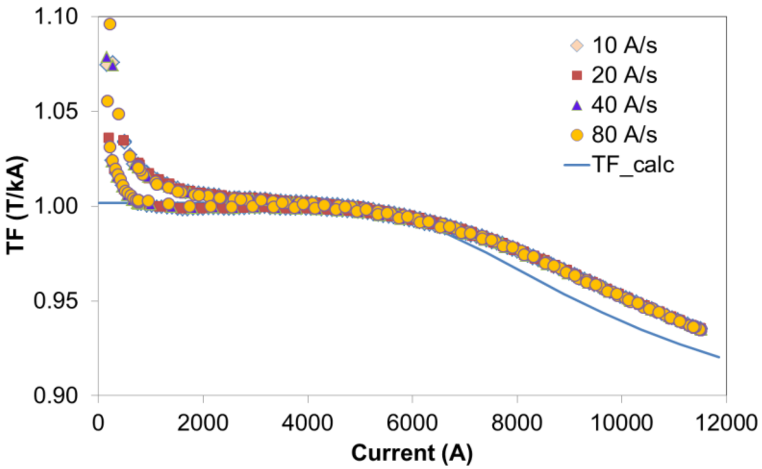


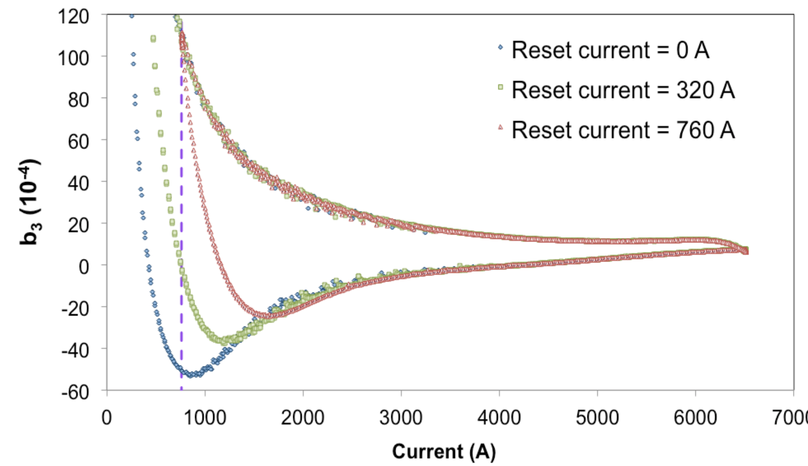
Maximum field 13.8/14.6 T in 38-100 mm aperture at 4.5/1.9 K

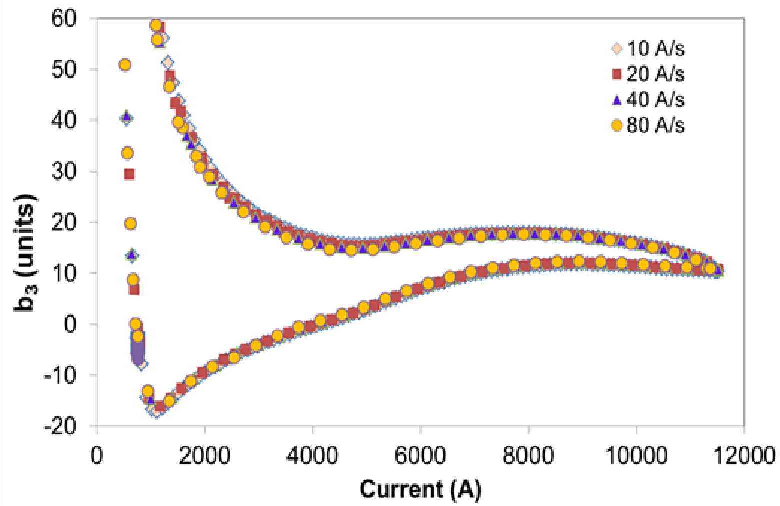
- long training
- ~10% degradation
- ramp rate sensitivity minimized by using SS core

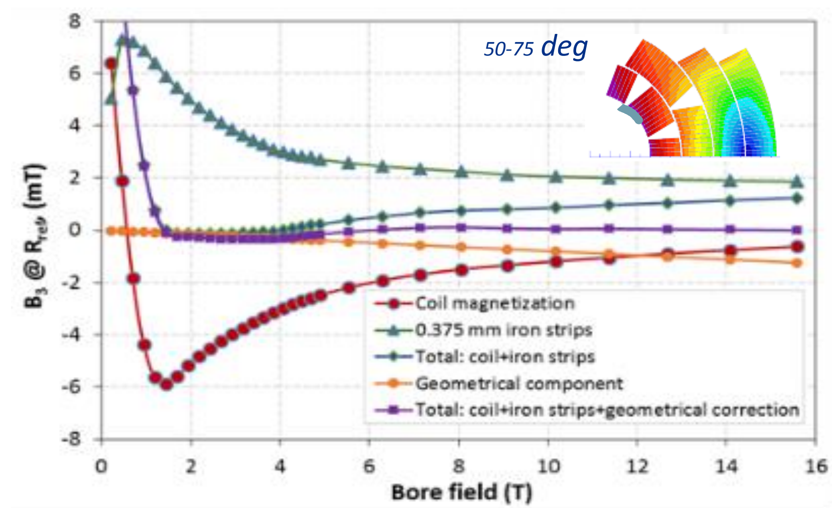


Nb_3Sn magnet field quality









- Coil magnetization and iron saturation effects are well understood and effectively corrected

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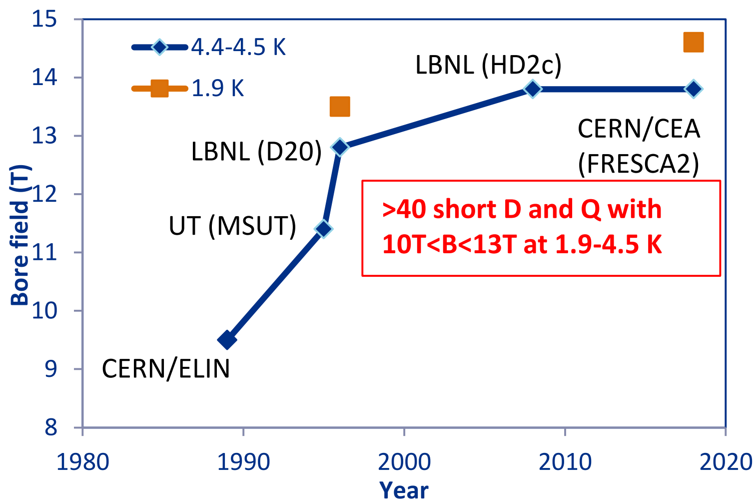
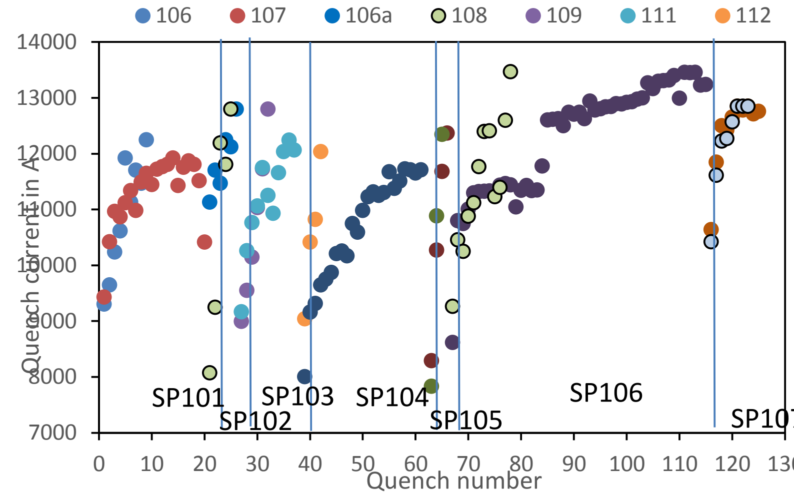
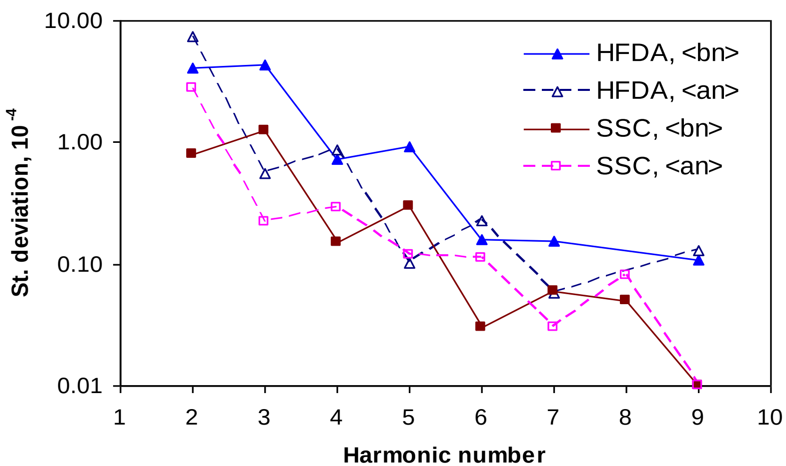
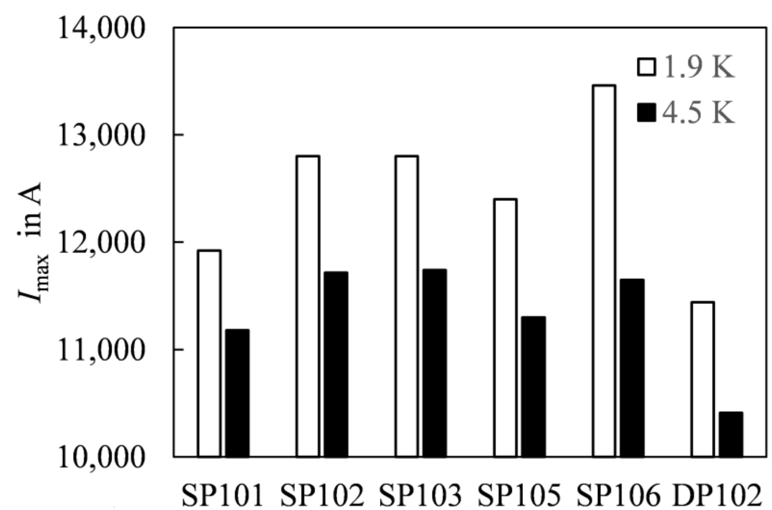
Performance reproducibility







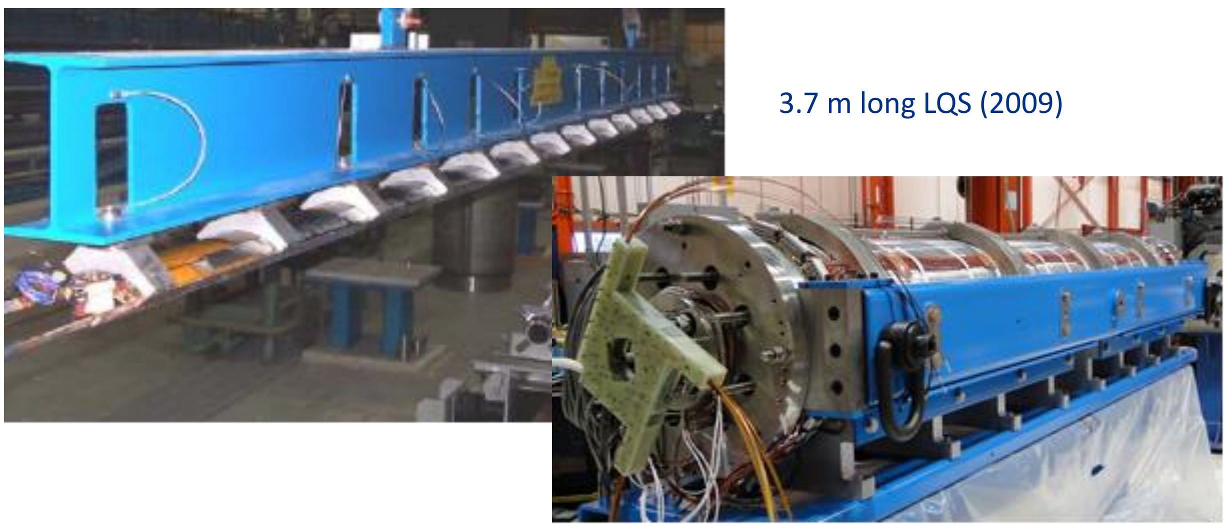


- Still large variations of magnet training and B_{max}
- good reproducibility of FQ

Technology scale up

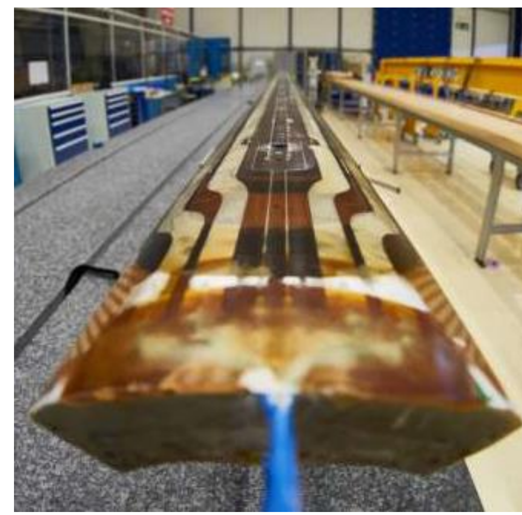
First 4 m long Nb_3Sn dipole coil (2008)

The first 5.5 m long 11 T MBH dipole prototype in its cryostat at CERN. (2018)



3.7 m long LQS (2009)

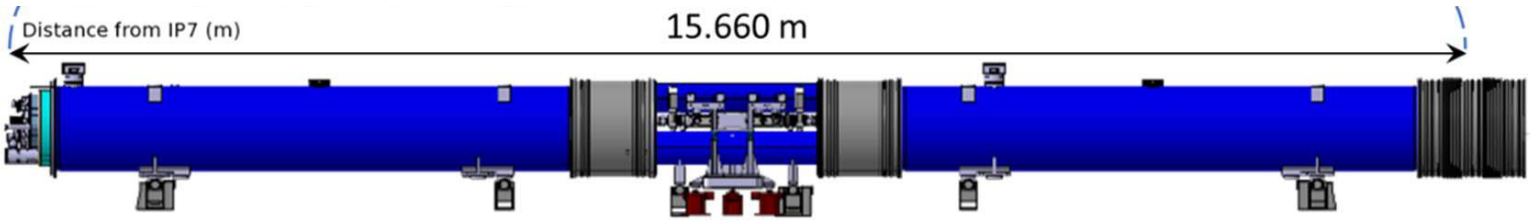
7.15 m long Nb3Sn quad coil (CERN)

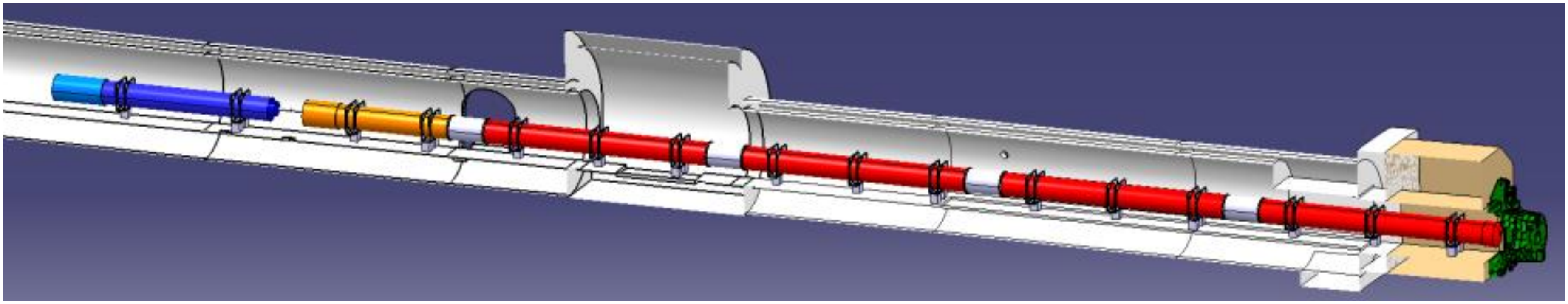


Long coil performance is being optimized

Application in accelerators

- 2019-2020 (LS1) – 1 (or 2) 11 T dipole assembly near IP7
  - total length of Nb3Sn magnets ~11-22 m
- 2024-2025 (LS2) – 4 triplets around IP1 (ATLAS) and IP5 (CMS)
  - total length of Nb3Sn magnets ~130 m

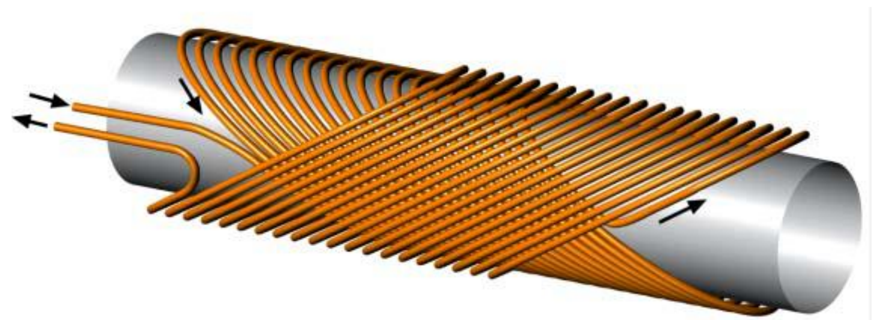


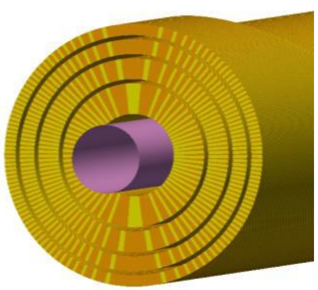


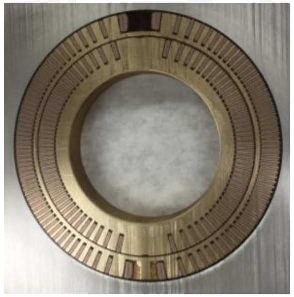
Nb_3Sn accelerator magnet R&D

- Quench performance improvement
  - High J_c wire with APC (FNAL/OSU/Hipertech) – increase margin
  - High C_p wire (FNAL/Hipertech/Bruker) – reduce sensitivity to perturbations
  - New epoxies – reduce perturbations
  - Stress management – reduce perturbations, minimize degradation

Canted cos-theta (CCT) MDP-LBNL







Slotted cos-theta (SCT) MDP-FNAL

Nb_3Sn magnets for JLEIC stage 2

- B_{nom}~12.3 T at 4.5 K
- Aperture: ~100 mm
- The field level in 100 mm aperture has been demonstrated
  - FRESCA: B(4.5K)=13.8 T in 100 mm bore
  - Design optimization is needed
    - with 20% margin => B_{des}~15 T
- Length: 2 x 4 m canted 2 degrees, or 8 m curved
  - ~4-8 m long coils are being produced and used
    - curved magnets are possible but need to be demonstrated
    - quench performance optimization to be done
- These magnets may also need stress management

Summary

- Nb_3Sn high field accelerator magnet technology made significant progress during past 25 years
  - quite well understood, reliable, reproducible, scalable
- Application in LHC is planned for this year
- Parameters for JLEIC Stage 2 magnets are realistic and achievable
- Focused R&D (~3-5 years) is needed to optimize magnet parameters, technology and cost
  - collaboration with US-MDP would help
- Nb_3Sn magnet production capabilities will be available in US and Europe after completion by ~2025 of the HL-LHC project