DE LA RECHERCHE À L'INDUSTRIE

Accelerator Magnets

E. Rochepault
With contributions from H. Felice, C. Lorin

Large Hadron Collider

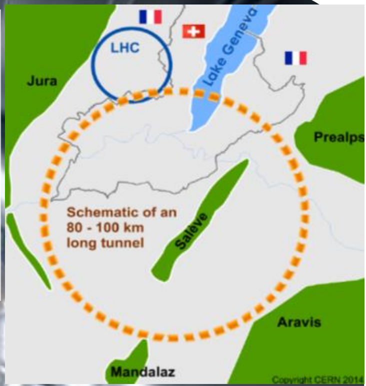
2013 Nobel Prize with the discovery of the Higgs Boson

Reliable operation at 6.5 TeV (13 TeV c.o.m)
Dipole Bore field: 7.7 T

Target 7 TeV (14 TeV c.o.m)
Dipole 8.33 T

FCC-hh
Future Circular Collider

100 km - **16 T**
100 TeV (c.o.m)



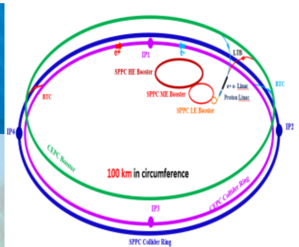
Courtesy of CERN

H. Felice, "Advances in Nb3Sn Accelerator Magnets", MT26

HL-LHC :
High Luminosity LHC

- **Focusing triplet**: Gradient of 132.6 T/m in a 150 mm bore
- **11 T Bending dipoles** to allow space for new collimators

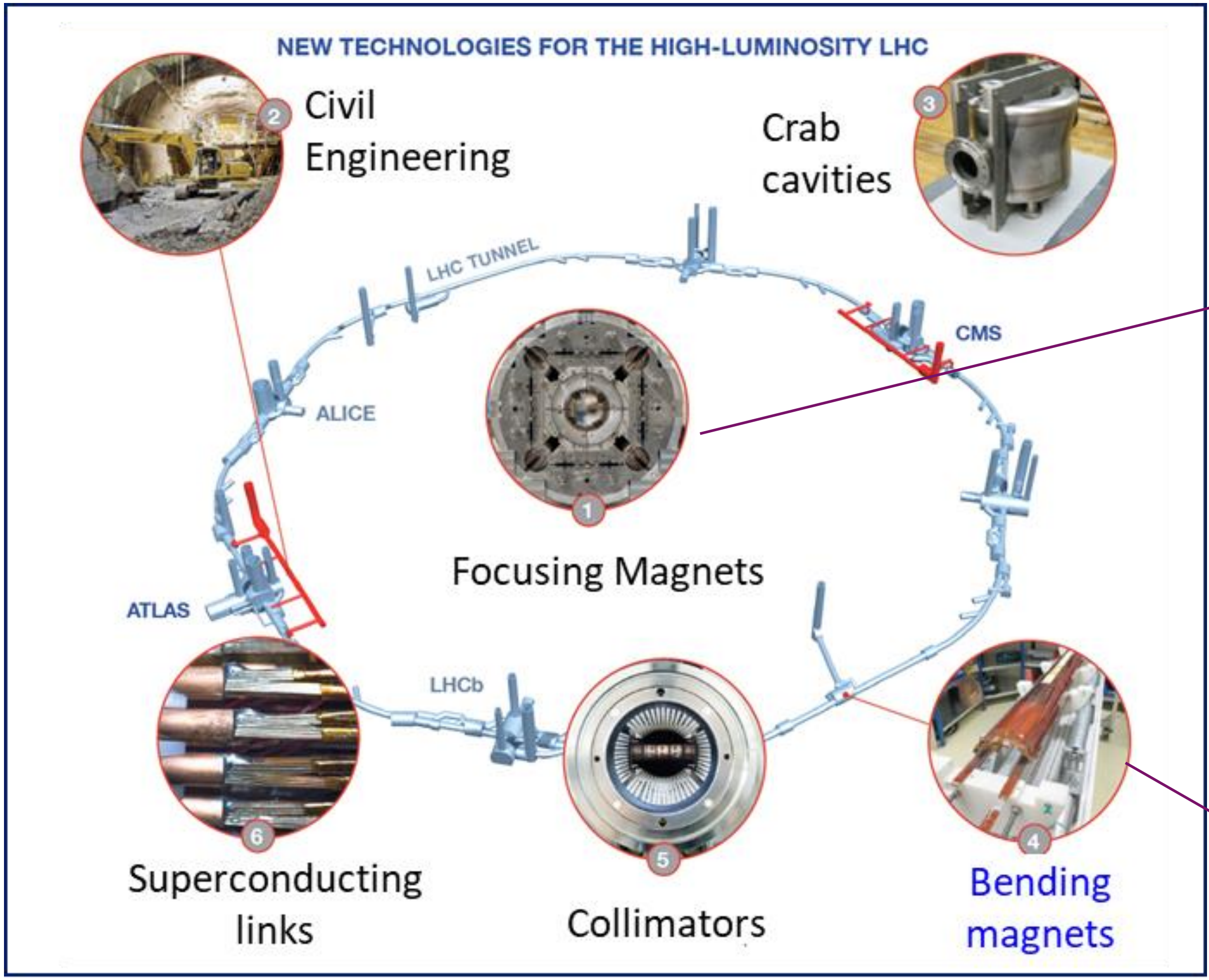
SPPC
Super Proton-Proton Collider



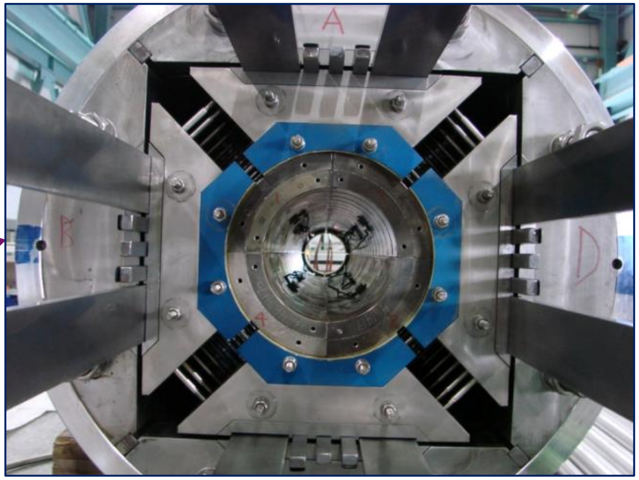
100 km - **12-24 T**
75 to 150 TeV (c.o.m)

Courtesy of Q. Xu, IHEP

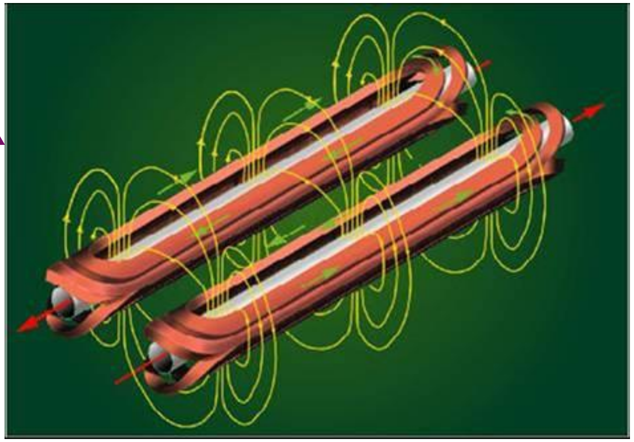
Magnets required in Accelerators



- Quadrupoles for focusing



- Dipoles for bending



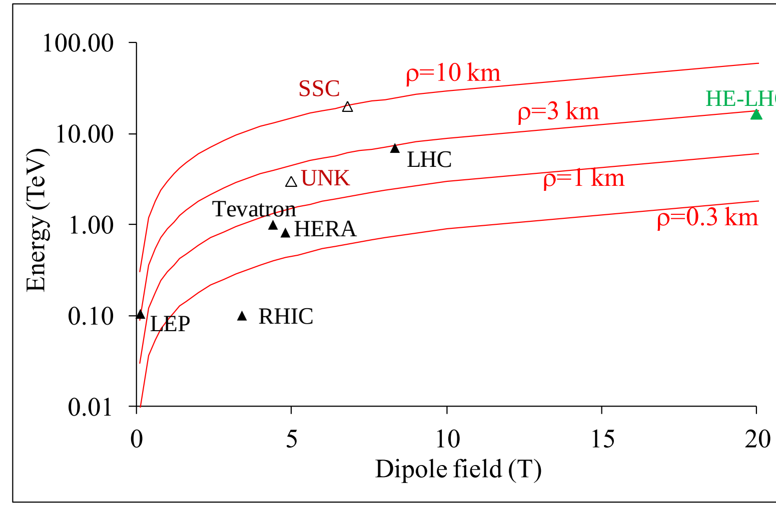
- Sextupoles and higher orders for correction

THE NEED FOR SUPERCONDUCTORS

- The beam energy:

  E [GeV] = 0.3 x B[T] x ρ[m]

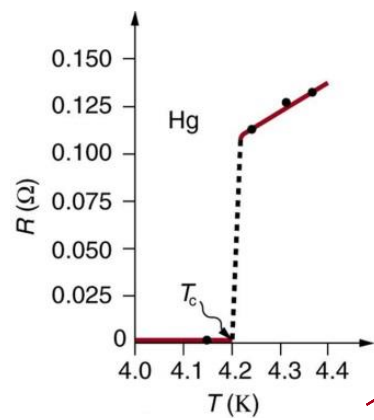
  → High energy → high field

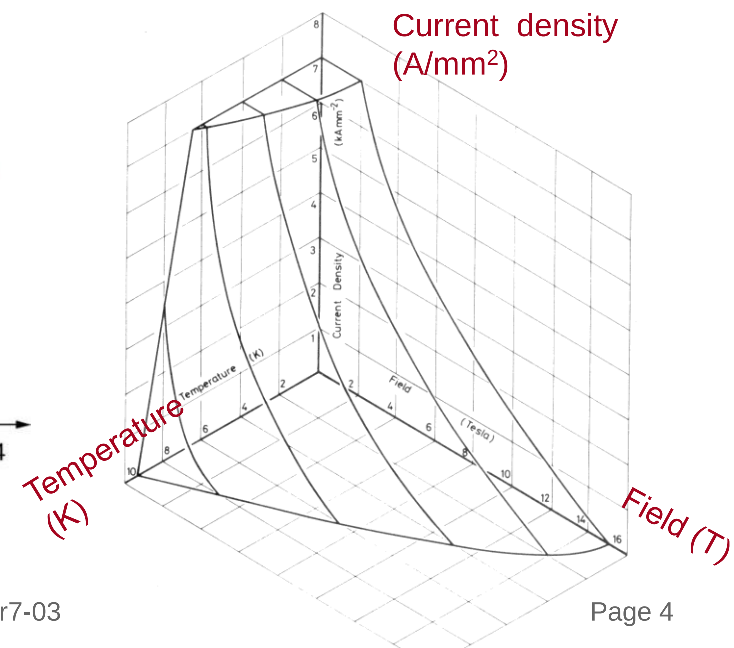


Courtesy of Ezio Todesco (CERN)

- Advantages of superconductors:
  - **R = 0 → no power consumption**
  - **High current for high field**
  - **Compact coils**

- Cons:
  - **Cost**
  - **Delicate fabrication**
  - **Need cryogenics**





NbTi Magnets in LHC

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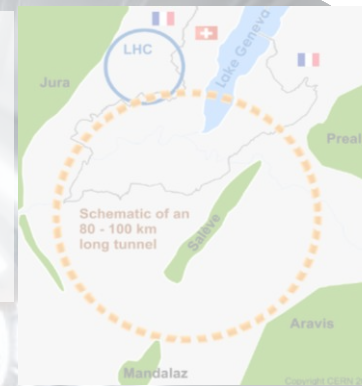

Courtesy of CERN

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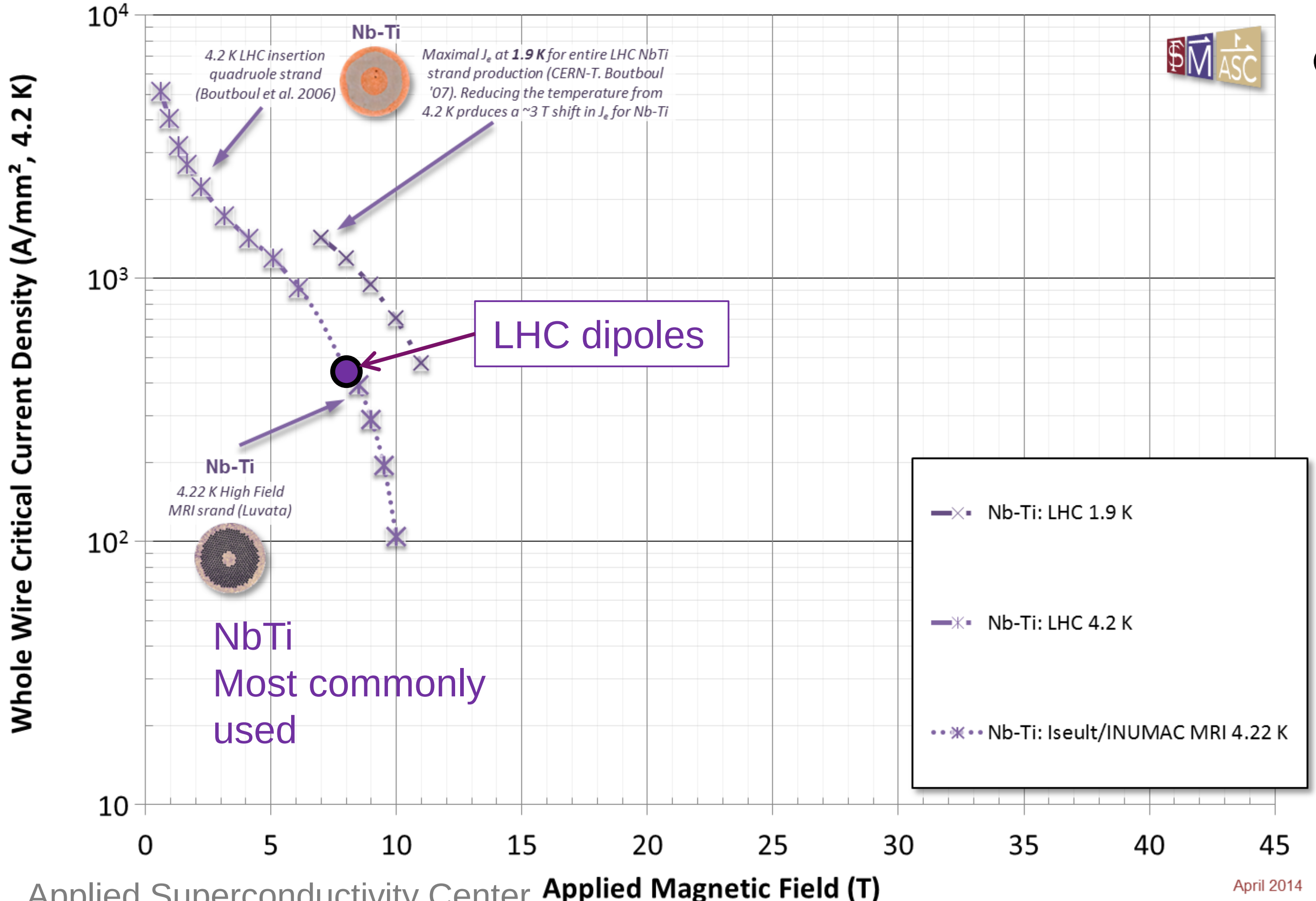
Courtesy of Q. Xu, IHEP

NbTi Magnets in LHC



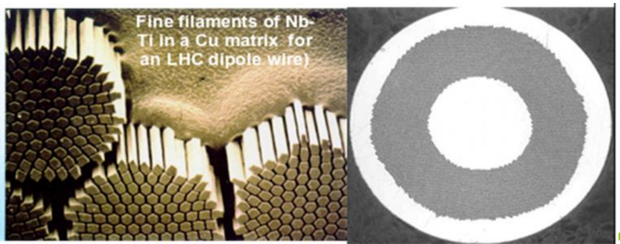
Magnet operating points :

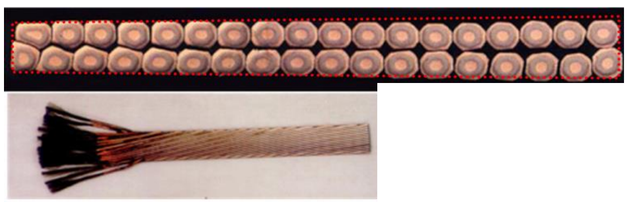
● LHC

P. Lee et al., Applied Superconductivity Center

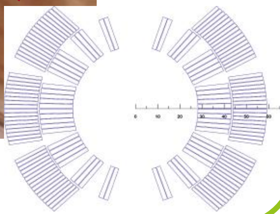
NbTi Magnets in LHC

1. Wires made of NbTi filaments in Cu matrix



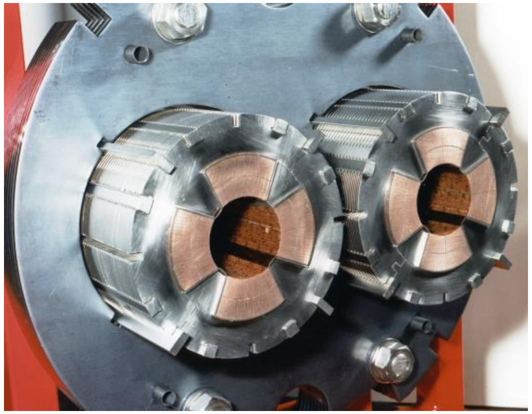


2. Rutherford Cable



3. Coils wound with cables

4. Coils assembled in the support structure



5. Assembly in cryostat

HL-LHC: 1ST USE OF NB_3SN IN ACCELERATORS

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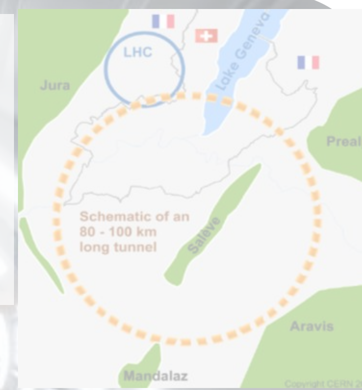
100 TeV (c.o.m)



Courtesy of CERN

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High Luminosity LHC

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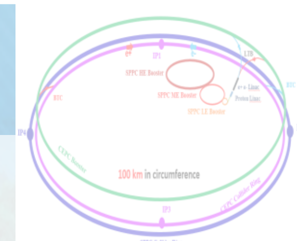
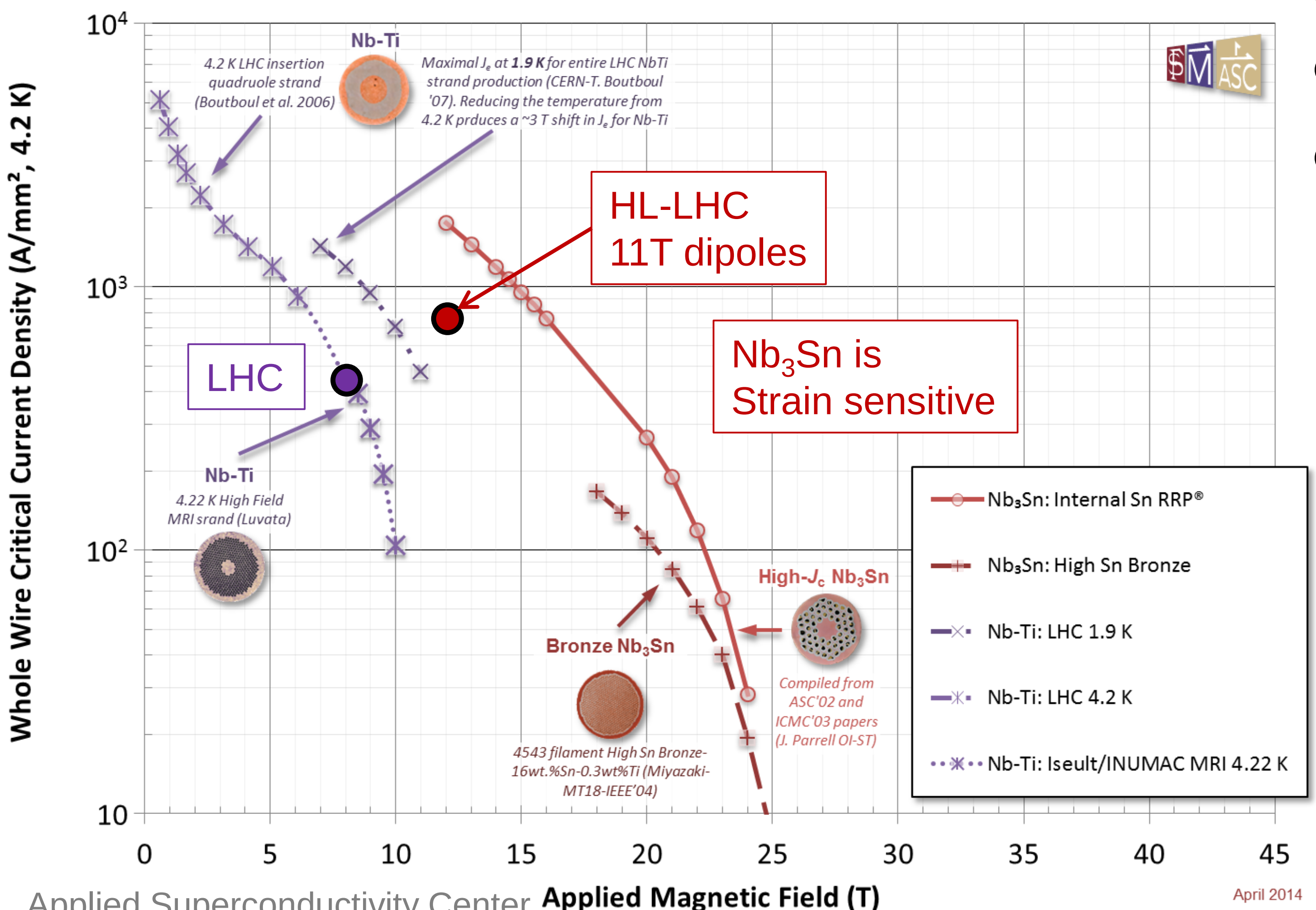


100 km - **12-24 T**
75 to 150 TeV (c.o.m)

Courtesy of Q. Xu, IHEP

HL-LHC: 1st Use of Nb_3Sn in Accelerators



P. Lee et al., Applied Superconductivity Center

Magnet operating points :

- LHC
- HL-LHC

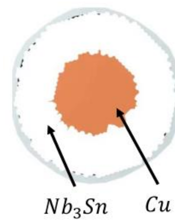
HL-LHC: 1st Use of Nb_3Sn in Accelerators

1. Wires made of Nb filaments +Sn in Cu matrix

2. Rutherford Cable

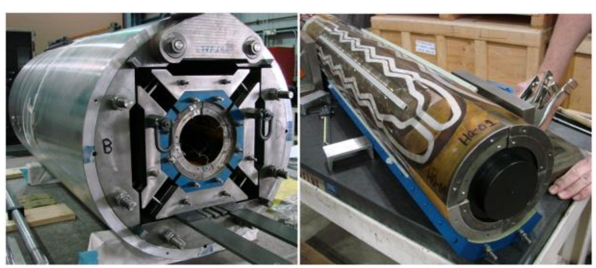
3. Coils wound with cables

4. 650°C heat treatment to form the Nb_3Sn phase



5. Coils impregnated with epoxy resin

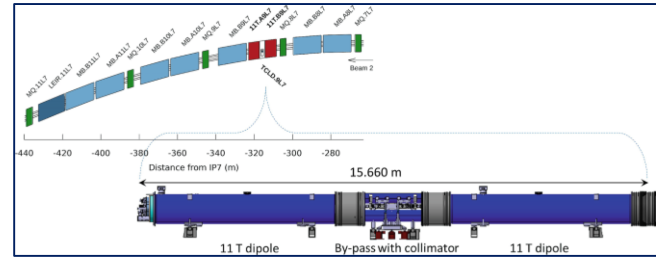
6. Coils assembled in the support structure

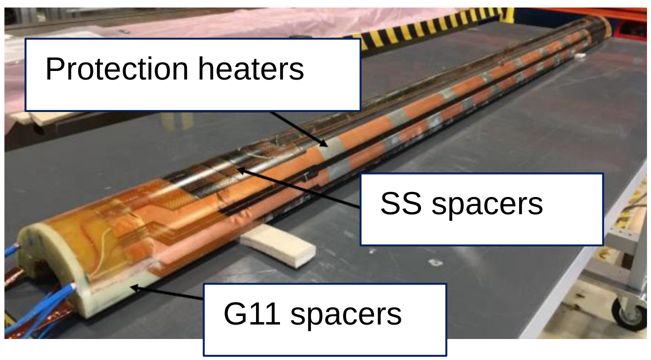


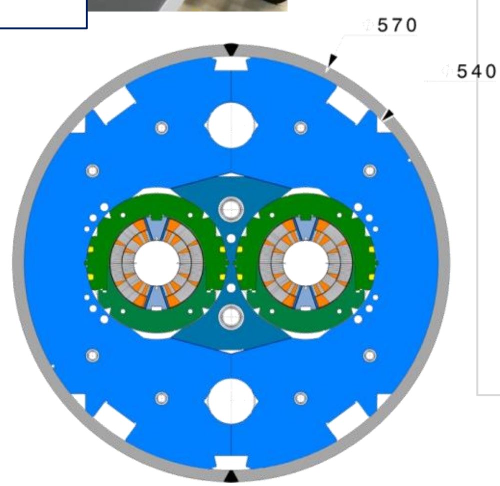
7. Assembly in cryostat

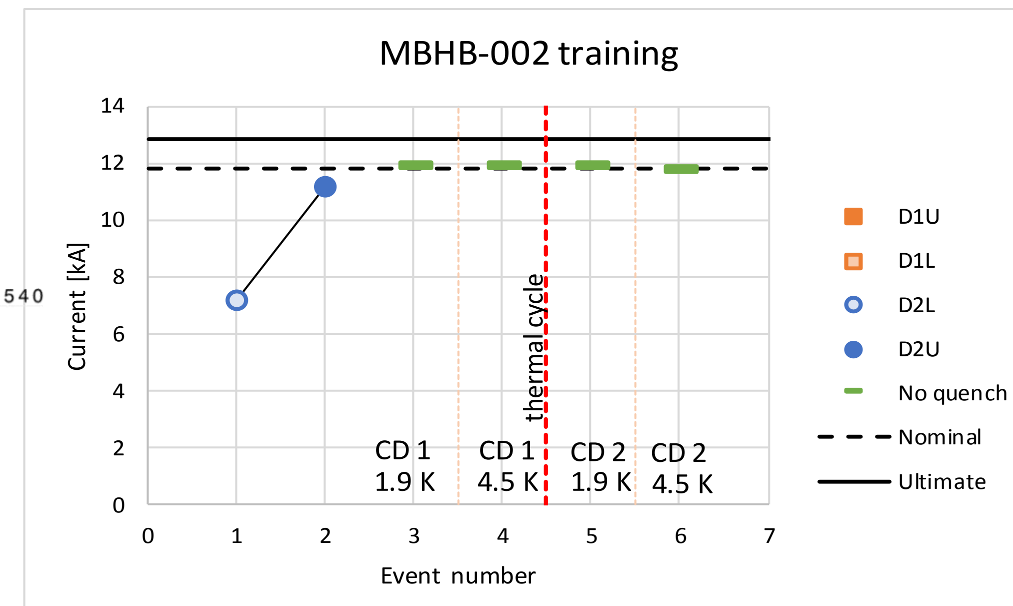
HL-LHC: 1ST USE OF Nb_3Sn IN ACCELERATORS

1. **11T project**: replace a 8T dipole with 2 11T dipoles → Save space for a collimator
   - **1st dipole reached nominal → ready for tunnel in 10/2019**
   - All four dipoles should be ready in April 2020







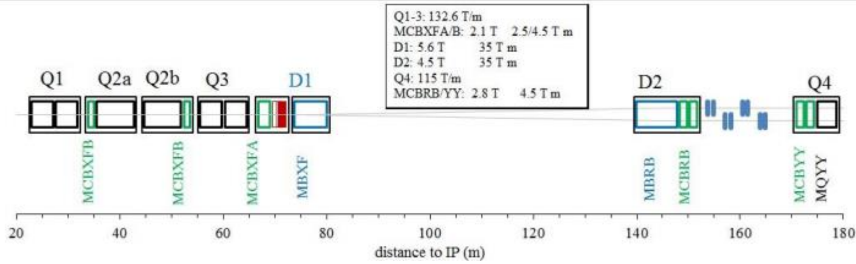


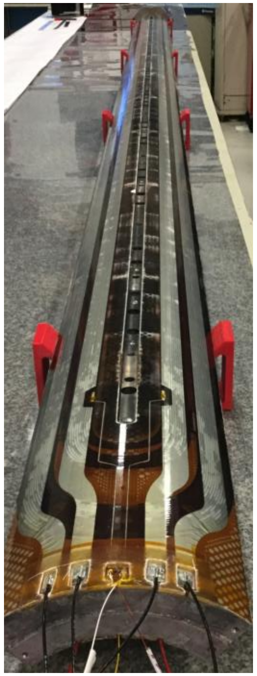
H. Felice, "Advances in Nb3Sn Accelerator Magnets", MT26

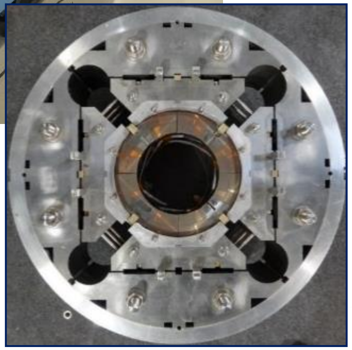
HL-LHC: 1ST USE OF Nb_3Sn IN ACCELERATORS

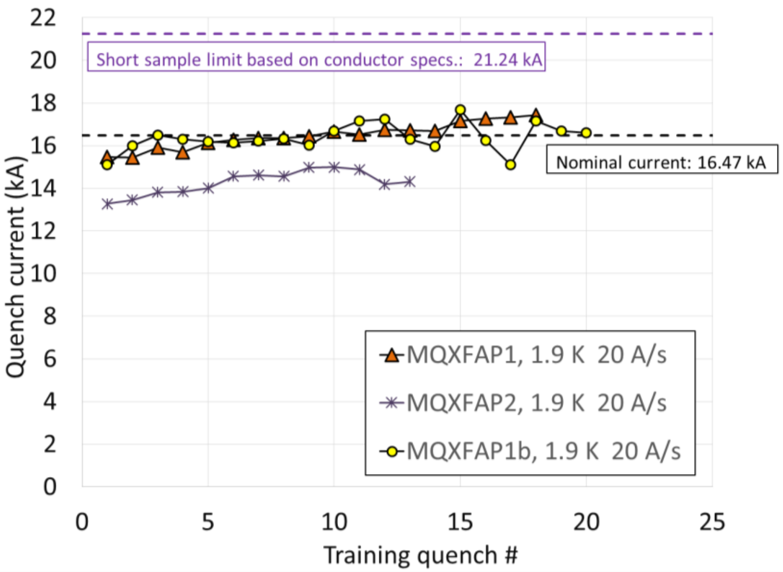
2. MQXF project: install high gradient/high aperture quadrupoles in the insertion regions

- **2 MQXFA prototypes tested**
- Pre-series on its way
- Other prototypes to be tested
- Installation foreseen 2024-2025









H. Felice, "Advances in Nb3Sn Accelerator Magnets", MT26

High Field Nb_3Sn Magnets for FCC

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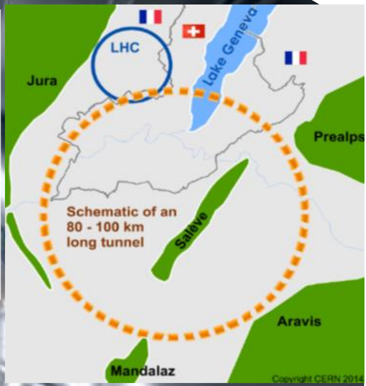

Courtesy of CERN

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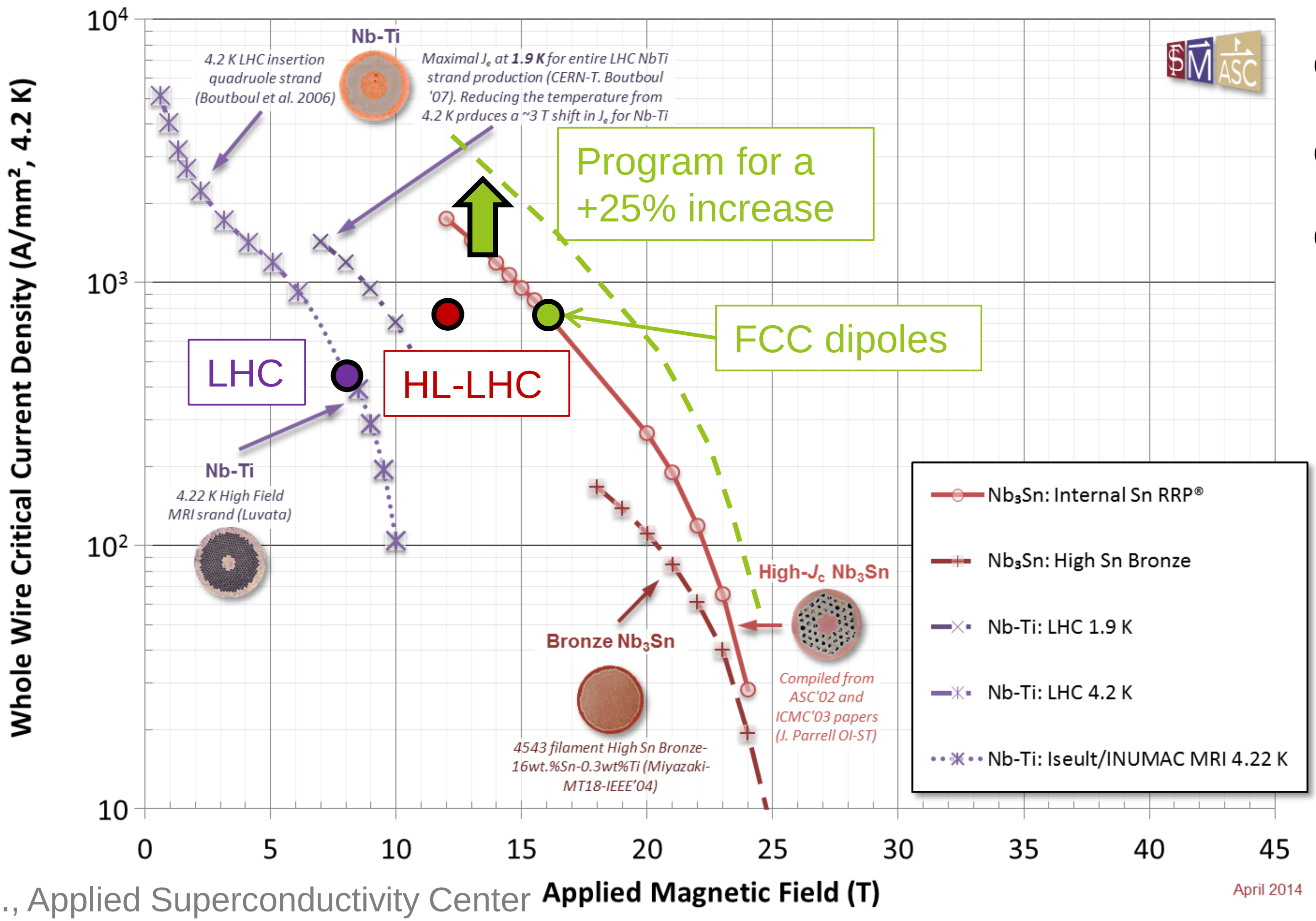
HIGH FIELD Nb_3Sn MAGNETS FOR FCC



P. Lee et al., Applied Superconductivity Center

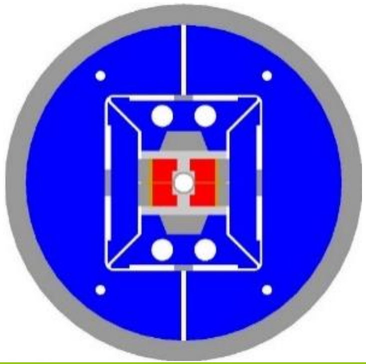
Magnet operating points :

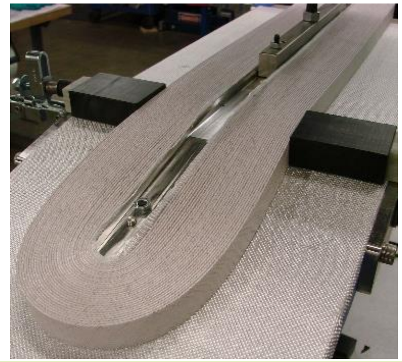
- LHC
- HL-LHC
- FCC

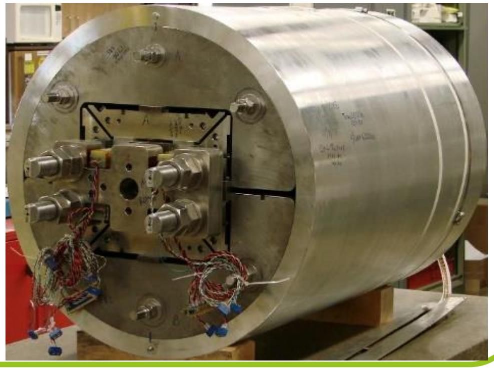
THE QUEST TOWARDS HIGH FIELD

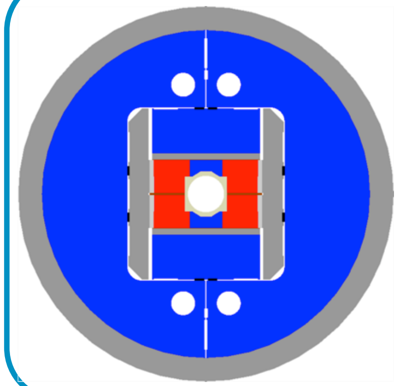
- **HD2 (LBNL)**

R&D magnet,
→ **13,8 T** in 2008



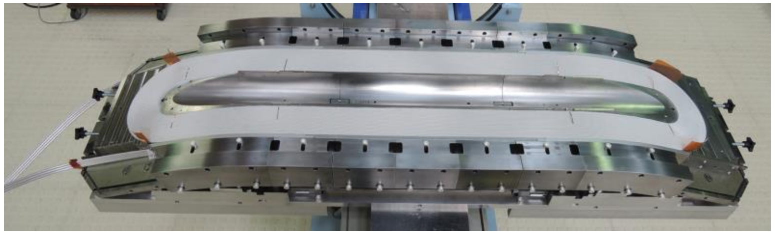


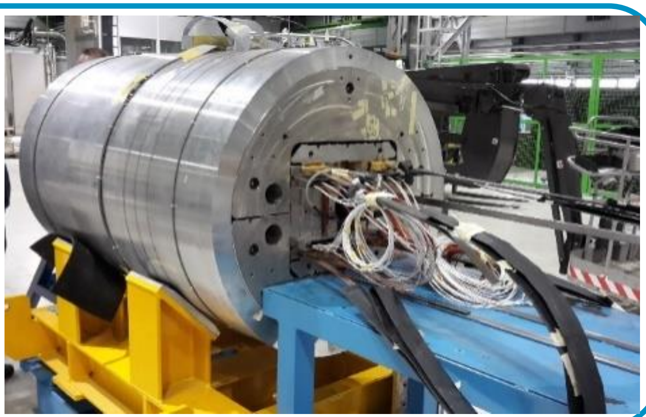




- **FRESCA2 (CERN/CEA)**

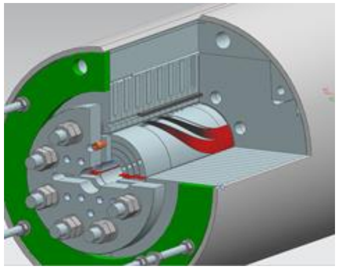
test station magnet → **14,6 T** in 2018

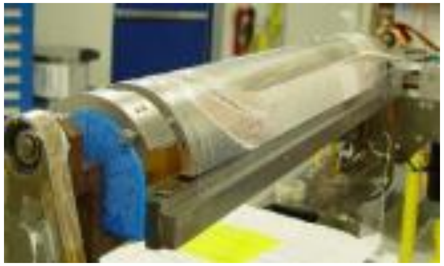




- **Fermilab 15T dipole**

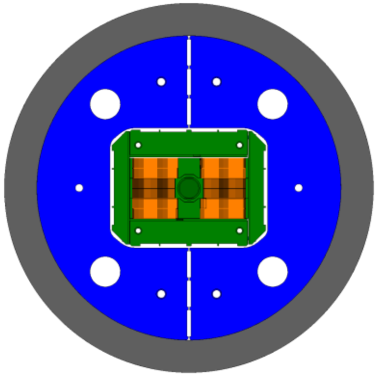
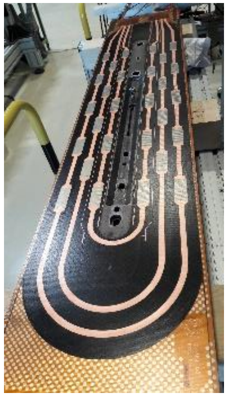
R&D magnet,
→ **14,1 T** in 2019
2nd test ongoing



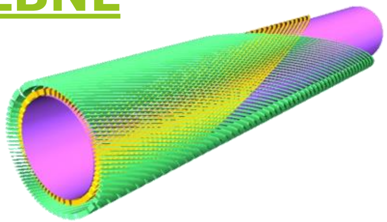


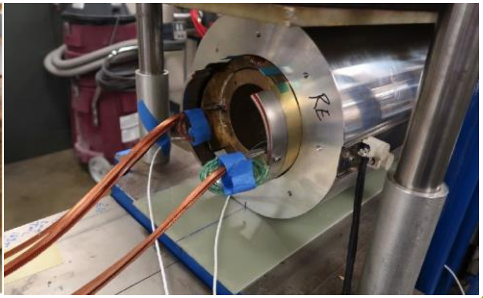
FCC: FUTURE HIGH FIELD Nb_3Sn MAGNETS

- **CERN R&D: RMM**
- Racetrack Model Magnet
- 16 T model, flat coils
- Different assemblies
- Fabrication ongoing

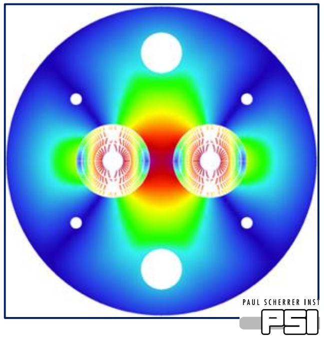



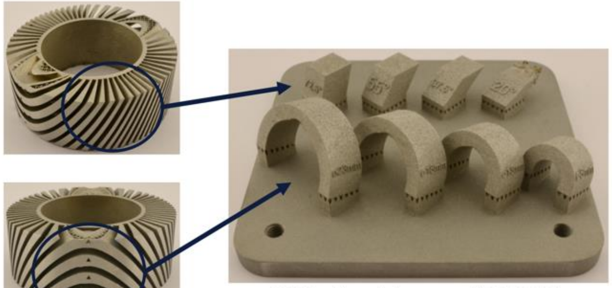
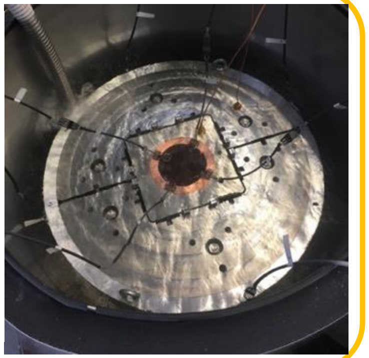

- **The Canted Cosine Theta (CCT) concept - LBNL**
- New technology
- Short models
- Tests ongoing





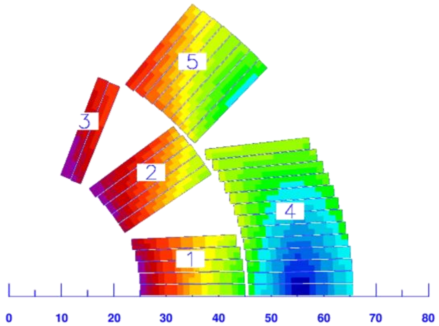
- **CCT R&D (PSI)**
- Following LBNL concept
- Short models
- Fabrication ongoing

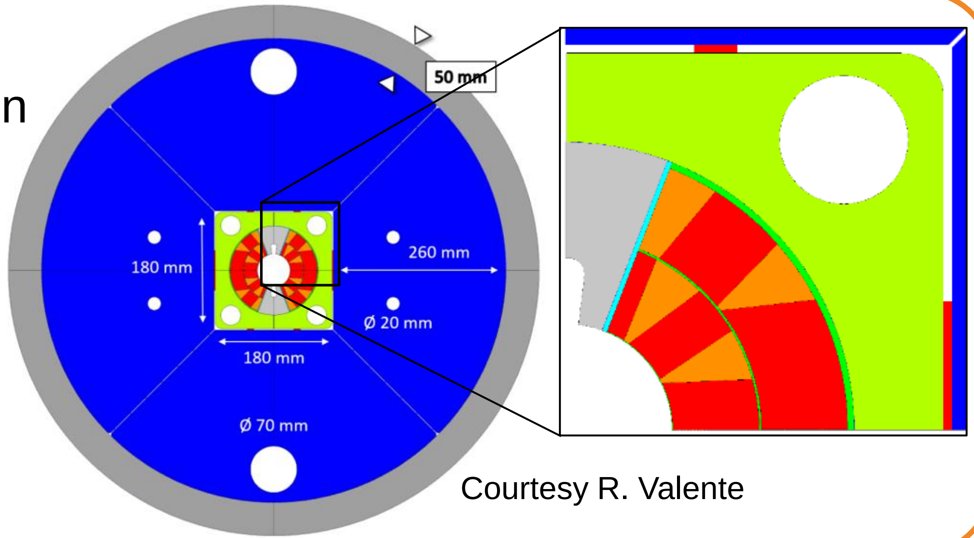



SLM with stainless steel (CL 20ES)


FCC: Future High Field Nb_3Sn Magnets

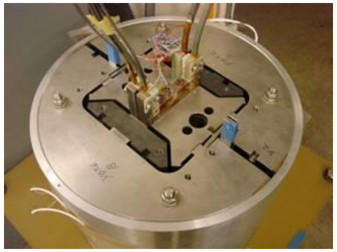
- **Falcon: CERN/INFN model**
  - 14 T demonstrator, conceptual design
  - 16 T concept for FCC

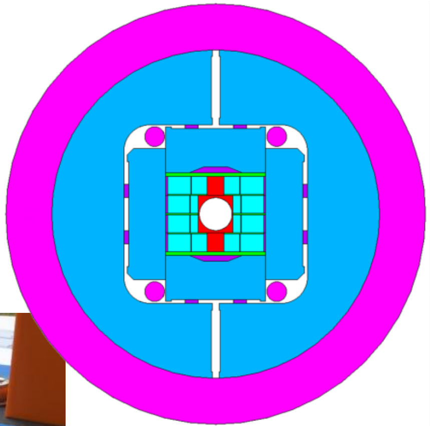


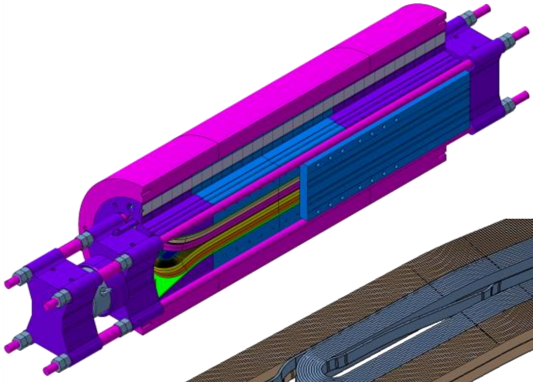


Courtesy R. Valente

- **F2D2: CERN/CEA model**
  - 15 T demonstrator, engineering design+mockups
  - 16 T concept for FCC



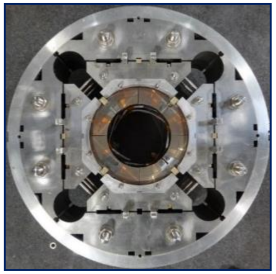




Conclusion

- Superconducting magnets required in accelerators:
  - **Compact, high current, low power consumption**

- NbTi technology mastered in accelerators:
  - **Used at a large scale,** best example is LHC
  - **But: limited practically to 8 T**

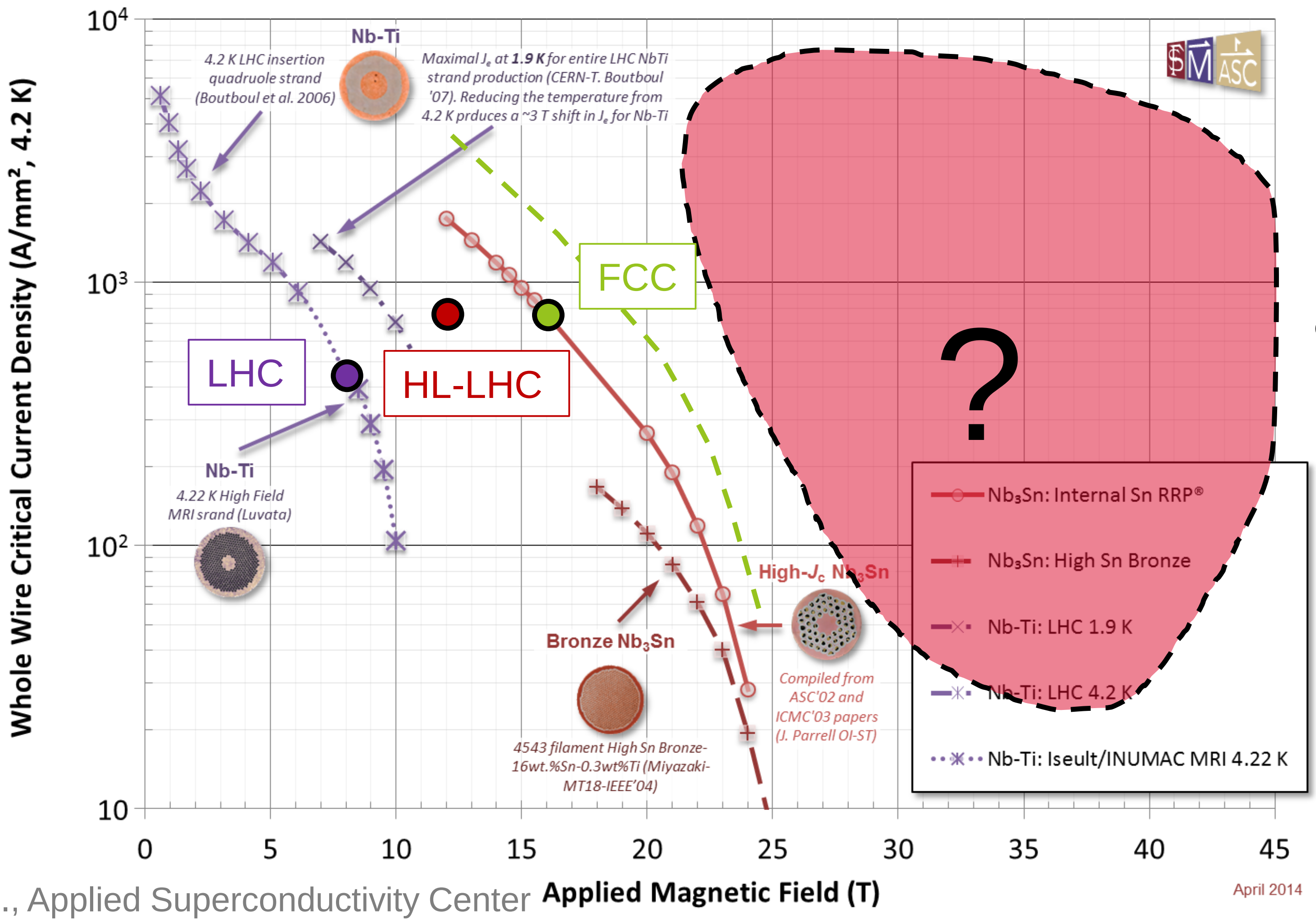


- Nb_3Sn technology mature:
  - **Difficult coil fabrication**
  - **Used for the 1^{st} time in HL-LHC**, 11-12 T

- Nb_3Sn for future accelerators:
  - FCC: **challenging 15-16 T goal**

    → strong R&D ongoing
  - **Model magnets reached 14-15 T**

AND BEYOND Nb_3Sn, ABOVE 16T ?



Magnet operating points :

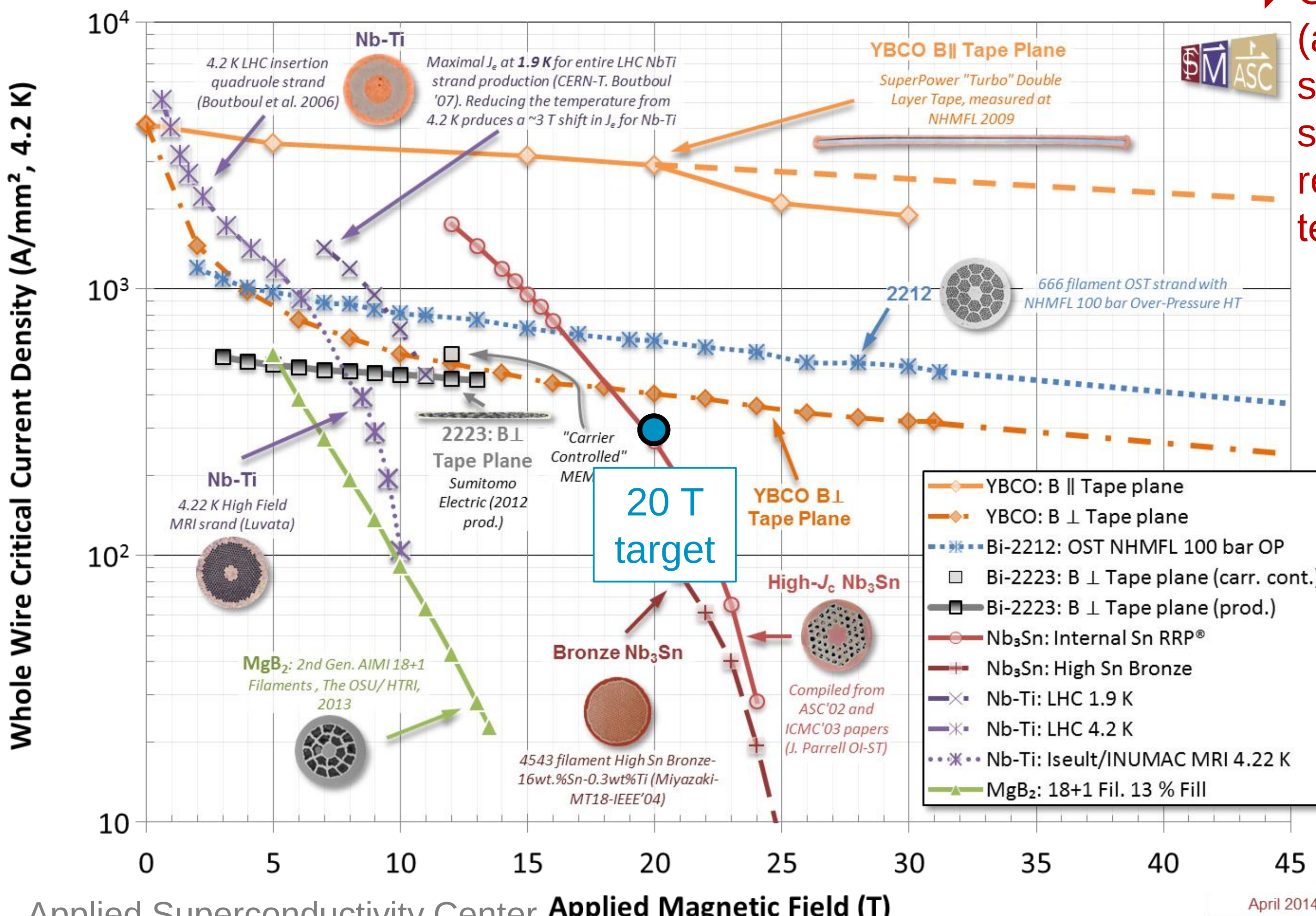
- LHC
- HL-LHC
- FCC

P. Lee et al., Applied Superconductivity Center

And beyond Nb_3Sn, above 16T ?

250$/kg | x10 | x10

Cost
Complexity
(anisotropy,
strain
sensitivity,
reaction
temperature…)



P. Lee et al., Applied Superconductivity Center

Magnet operating points :

- LHC
- HL-LHC
- FCC
- 20 T target

See “HTS magnets”, by T. Lecrevisse

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THANK YOU FOR YOUR ATTENTION!