Development of Nb_3Sn 11 T Demonstrator Dipoles for Accelerators

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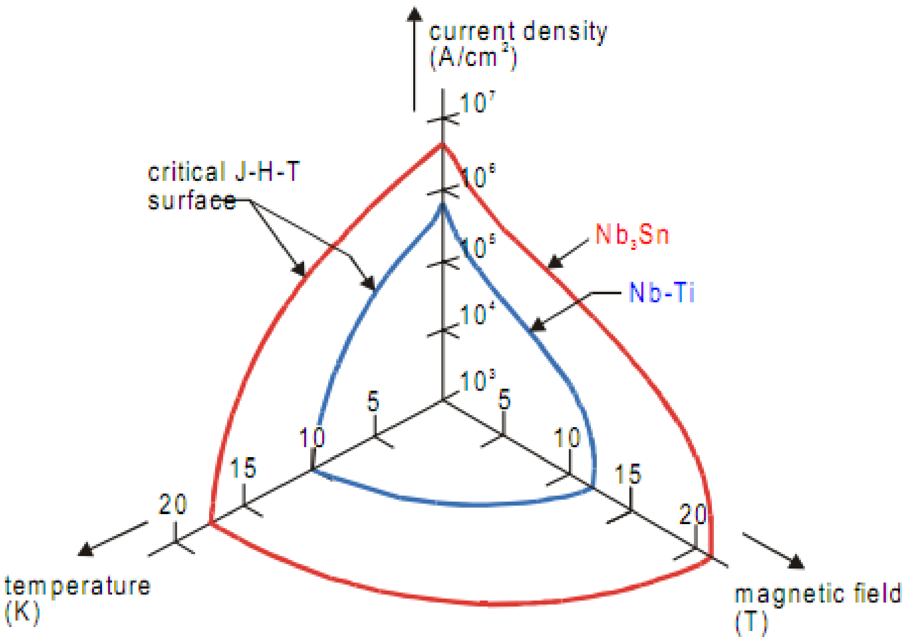
Outlines

- Progress of Nb_3Sn superconductor and accelerator magnet technology
- Nb_3Sn accelerator magnet R&D at Fermilab
- 11 T demonstrator magnets
  - Goals, approaches, design constraints
- Magnet design and parameters
- Field quality issues
- Conclusions

Nb_3Sn Superconductor

Nb_3Sn as superconductor is known since late 1950's.



- Nb_3Sn critical parameters (J_c, B_{c2} and T_c) are very attractive for accelerator magnets
- Nb_3Sn:
  - complicate HT to form the superconducting Nb_3Sn phase and obtain an optimal microstructure for high J_c
  - brittle, strain sensitive after reaction

Nb_3Sn is produced by industry since 1960-70 and used mainly in solenoids for various applications.

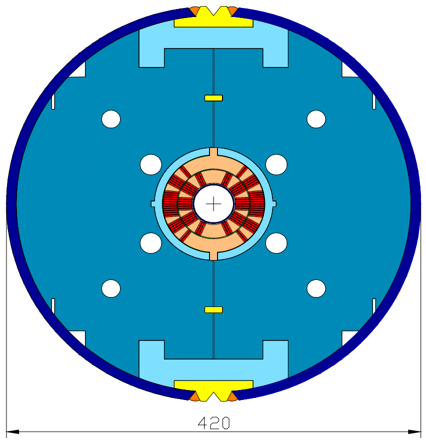
Nb_3Sn Accelerator Magnet R&D Progress

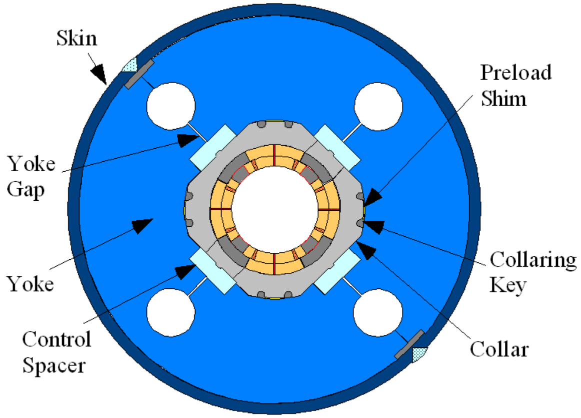
Year	Laboratory	Magnet type (name)	Results
1967	BNL	quadrupole	85 T/m (3 T)
1979	BNL	dipole	4.8 T
1982	CERN	quadrupole	71 T/m
1983	CEN/Saclay	dipole	5.3 T
1985	LBNL	dipole (D10)	8 T
1986	KEK	dipole	4.5 T
1988	BNL	dipole	7.6 T
1991	CERN/ELIN	dipole	9.5 T
1995	LBNL	dipole (hybrid D19H)	8.5 T
1995	UT	dipole (MSUT)	11.2 T
1996	LBNL	dipole (D20)	13.3 T
2003	LBNL	dipole (RD3c)	10 T
2004-6	Fermilab	dipole (HFDA05-07)	10 T
2008	LBNL	dipole (HD2)	13.4 T

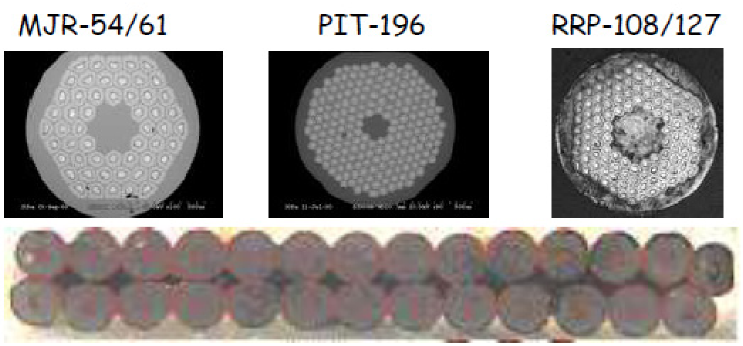
- **The present progress is the result of efforts supported and coordinated by the U.S. DOE during the past decade.**
- **Both the performance and the technological aspects of the Nb_3Sn strands and accelerator magnets were significantly advanced.**

Nb_3Sn Magnet R&D at Fermilab

- Nb_3Sn accelerator magnet R&D at Fermilab since 1999 focusing first on small aperture 10 T dipoles for VLHC
- Since 2005 focus on large aperture 200 T/m quads for the LHC upgrade.







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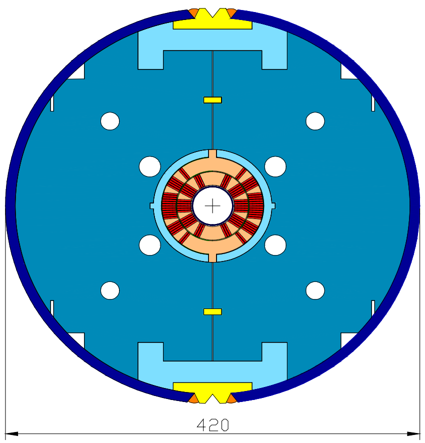

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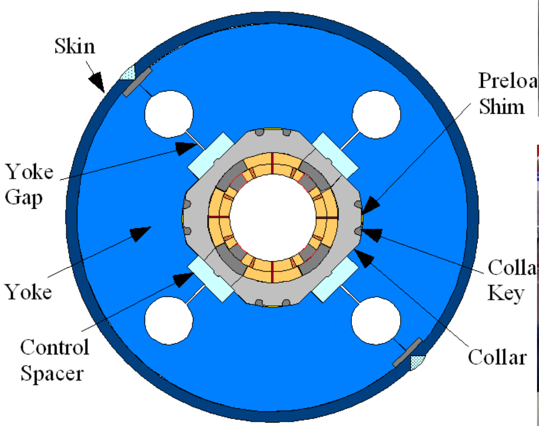

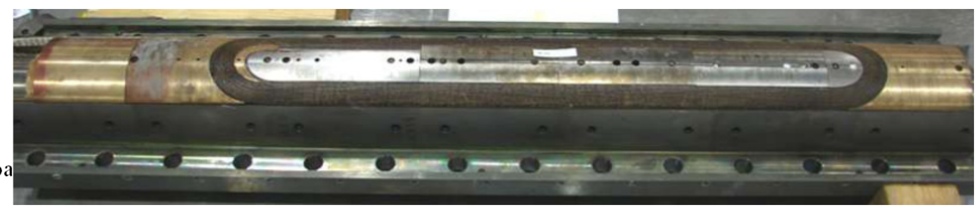

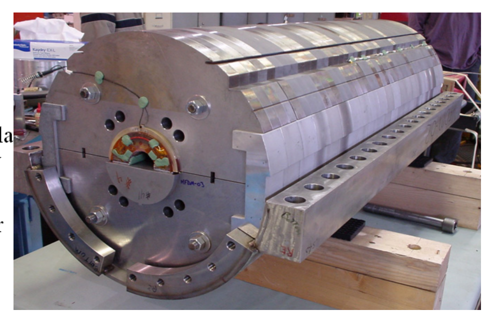

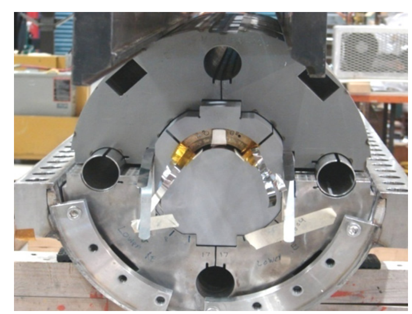

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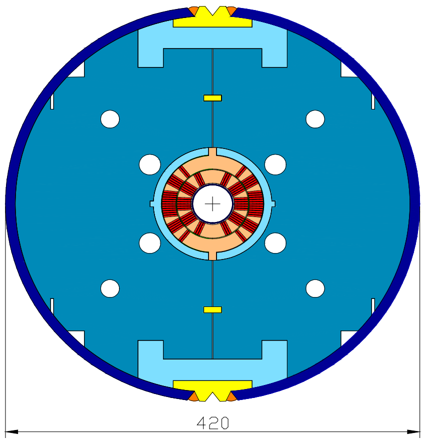

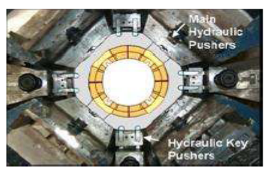

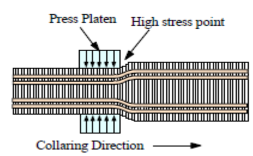

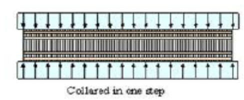

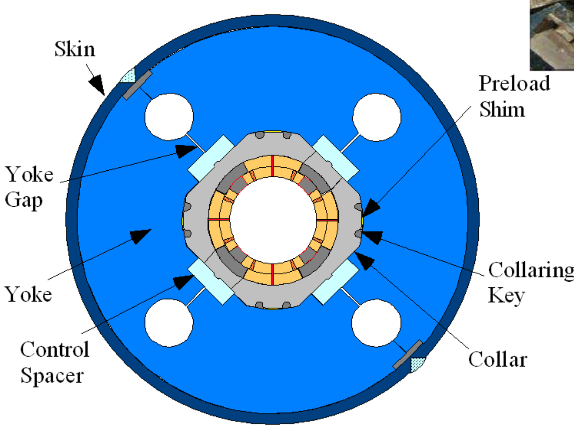

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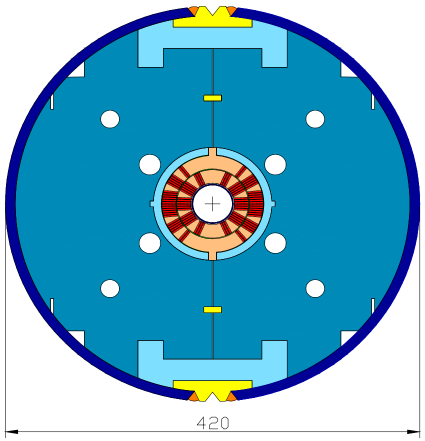

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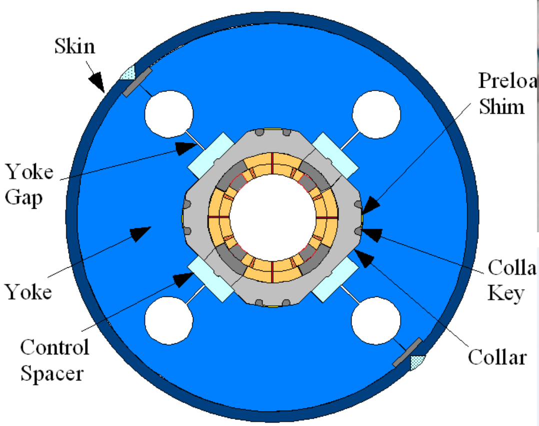
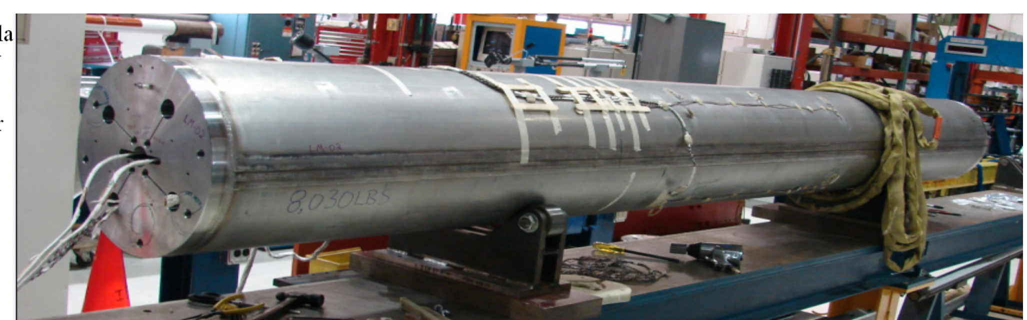




11 T Demonstrator Magnets

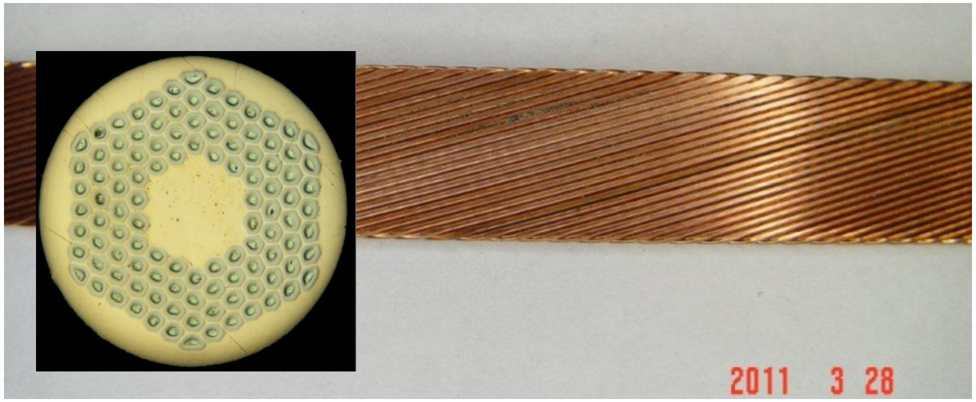
- Based on these results it is important to extend this success to dipole configurations.
- Fermilab and CERN have started a development program with the goal of building a **5.5-m long twin-aperture 11 T Nb_3Sn dipole** by 2014.
  - The first long 2-in-1 Nb_3Sn dipole
  - Possible use in LHC upgrades => additional design constraints
- The first phase is the design and construction of a 2-m long 11 T demonstrator magnets.
- The demonstrator magnets are designed to make maximum use of existing tooling, infrastructure and magnet components at both laboratories.

General Design Approach

- The magnet design concept features 2-layer shell-type coils, stainless steel collars, a cold iron yoke, surrounded by a stainless steel skin.
- To accommodate the beam sagitta in the long 11 T magnets and avoid the additional complication of curved Nb_3Sn coils, the coil aperture was chosen to be 60 mm.
- The single-aperture demonstrator magnet will use the modified 400-mm yoke from Fermilab's dipole models.
- The twin-aperture 11 T demonstrator magnet will use the modified 550 mm iron yoke from the LHC main dipole.

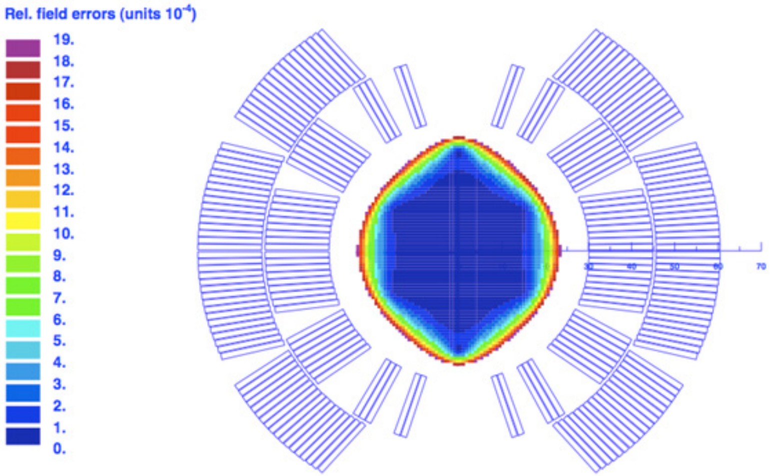
Table 1: Cable parameters

Strand and Cable



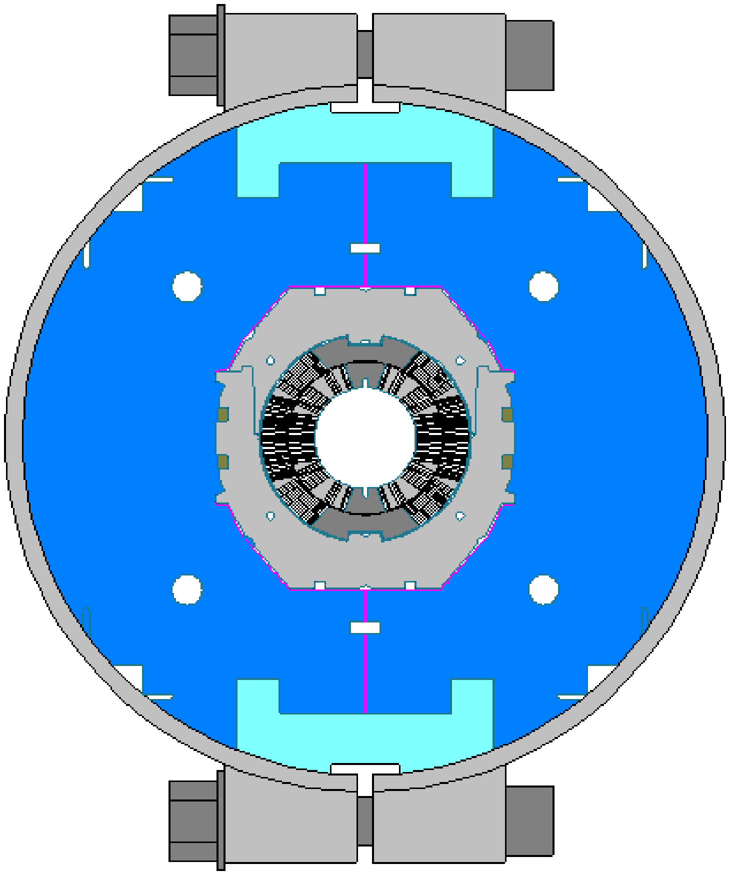
- **Strand:**
  - **Nb_3Sn RRP-108/127**
  - **0.7 mm diameter**
  - **high-J_c, stable, produced by industry (OST)**
- **Cable:**
  - **15-mm wide**
  - **40 strands**
  - **Large aspect ratio**
- **Cable insulation**
  - **2 layers of 0.075-mm thick E-glass tape**
- **250-m long pieces of Cu and Nb_3Sn cable were produced at Fermilab**

Coil Design



- **Coil optimization goals**
  - o **11 T at 11.85 kA with 20% margin at 1.9 K**
  - o **field errors below the 10^{-4} level**
- **6-block design**
  - o **56 turns, 21(35) turns in the inner (outer) layer.**
- **Coil winding tooling and parts were designed and procured.**
- **Practice coil winding has started.**

Mechanical Structure



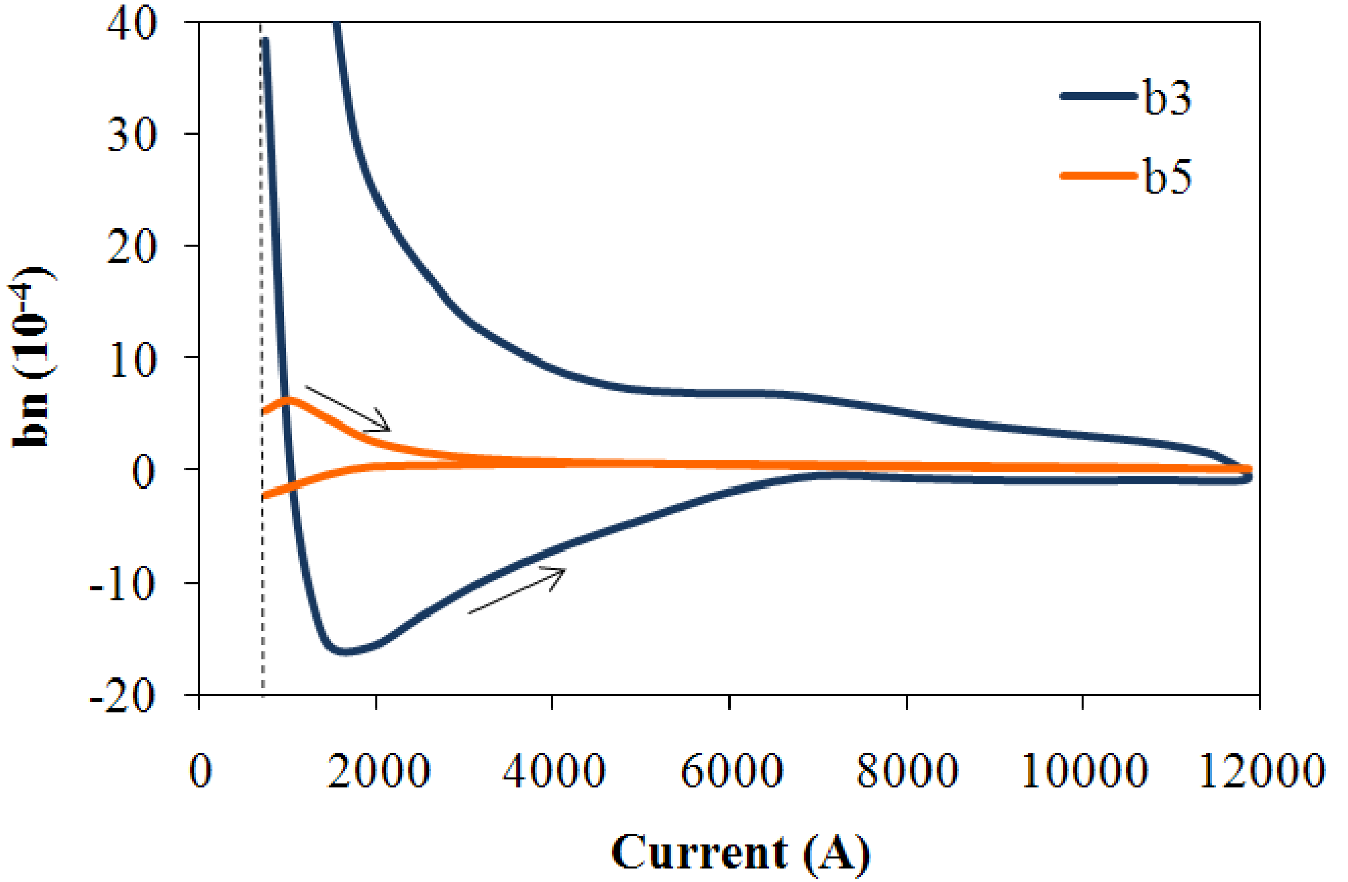
- The 25-mm thick slightly elliptical stainless steel collar.
- The vertically split iron yoke clamped with Al clamps.
- The 12-mm stainless steel skin.
- Two 50-mm thick end plates.
- The coil pre-stress at room temperature is 100 MPa to keep coil under compression up to 12 T.
- The mechanical structure is optimized to maintain the coil stress below 160 MPa - safe level for brittle Nb_3Sn coils.

The structure and assembly tooling design is in progress.

Magnet Parameters

Parameter	Value
Nominal current I_{nom}, A	11850
Nominal bore field, T	10.86(11.21*)
Current margin on load line at 1.9 K, %	20.9
Maximum design field, T	12.0
Short-sample bore field at 1.9 K, T	**13.62**
Inductance at I_{nom}, mH/m	5.56
Stored energy at I_{nom}, kJ/m	473
Fx per quadrant at I_{nom}, kN/m	2889
Fy per quadrant at I_{nom}, kN/m	1570
Coil length, m	**1.8**
Magnetic length, m	1.69

Field Quality



- Iron saturation effect is small due to thick collar.
- Persistent current effect is large due to large D_{eff}~50 μm in Nb_3Sn strand (compare with 6-7 μm in NbTi strands).

Conclusions

- 11 T Nb_3Sn demonstrator dipole magnets for possible use in accelerators in particular for the LHC upgrades are being developed by Fermilab/CERN collaboration.
- The engineering design of the single-aperture 2-m long magnet and fabrication tooling is nearly complete and first winding trials are in progress.
- The cold tests are planned towards the end of 2011
  - demonstrate the quench performance, nominal field, and operation margin
  - study field quality and define the D_{eff} and L_p of Nb_3Sn strand, the need of a stainless steel core in the cable, and parameters of passive field correction for the final design
- The conceptual design of the twin-aperture 11 T dipole magnet has been started.