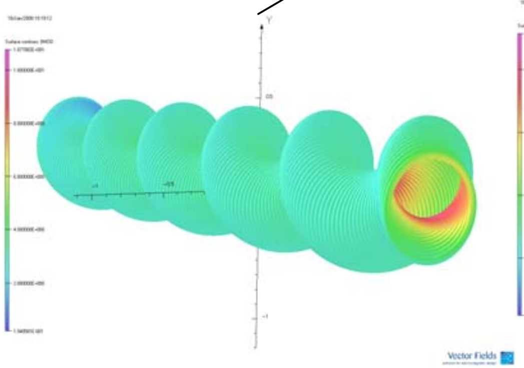
MCTF Magnet and HTS Conductor R&D

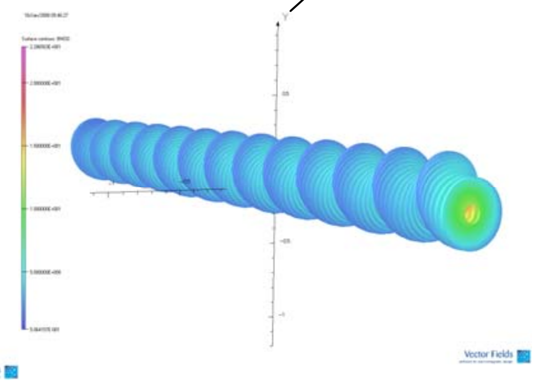
MCTF Magnet R&D Directions

- Magnet R&D (with Muons Inc.)
  - Conceptual design studies of Helical Cooling Channel Magnet System
  - Development of Helical Solenoid for Cooling Demonstration Experiment (CDE)
  - Very High Field Solenoid R&D
- R&D for SC Materials in support of magnet program (with National Labs and Industry)
  - Participation in National HTS Program
- Contribute where possible to the conceptual design of detector magnets

HCC Magnet System Design Studies

Parameter			Segment			
			1st	2nd	3rd	4th
L	Length	m	50	40	30	40
λ	Helix period	m	1.0	0.8	0.6	0.4
a	Ref. orbit radius	m	0.16	0.13	0.095	0.064
κ	Helix pitch		1.0	1.0	1.0	1.0
B_s	Solenoid field	T	-6.95	-8.68	-11.6	-17.4
b_d	Helix dipole	T	1.81	2.27	3.02	4.53
b_q	Helix quad	T/m	-0.35	-0.44	-0.59	-0.88





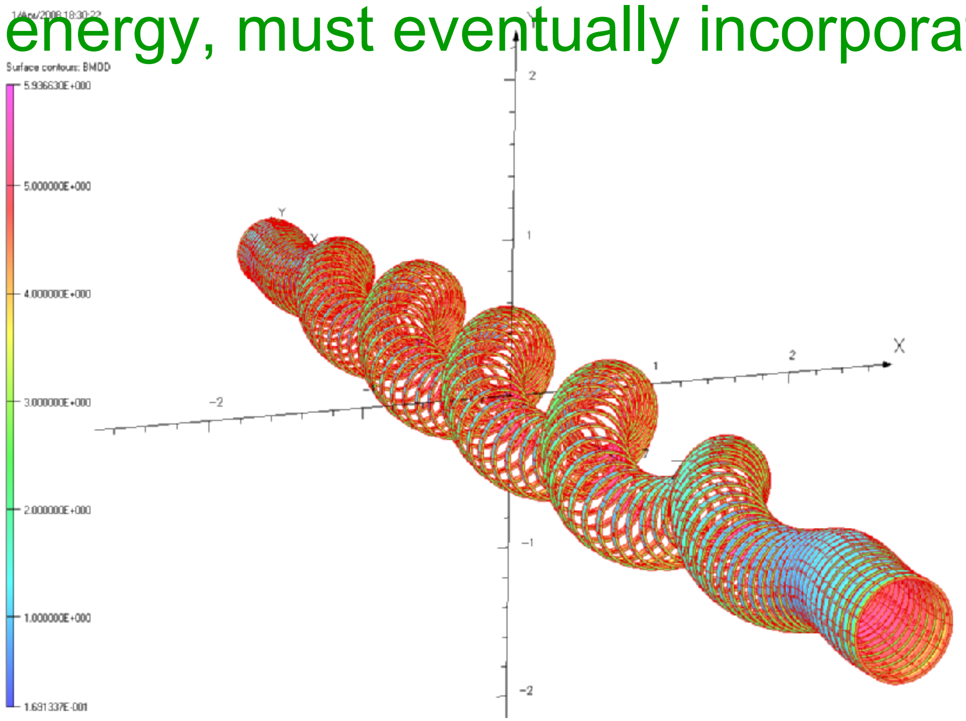
- The helical solenoid concept (Fermilab)
  - Alternative to straight solenoid with helical D and Q coils
  - Ring coils follow the helical beam orbit produsing solenoi-dal, helical D and Q fields
- Multi stage HCC study
  - Wide range of fields, helical periods, apertures
  - Straight solenoid concept does not work for high-field/small-aperture sections
  - Field tuning more complicate at high fields
  - NbTi, Nb3Sn/Nb3Al and probably HTS in final stage
- Studies will continue

HS for Cooling Demonstration Experiment

Goals: cooling demonstration, HS technology development

Features: SSC NbTi cable, B_{max}~6 T, coil ID ~0.5m, length ~10m

=> Complex magnet, significant magnetic forces and stored energy, must eventually incorporate RF.



Status: conceptual design complete

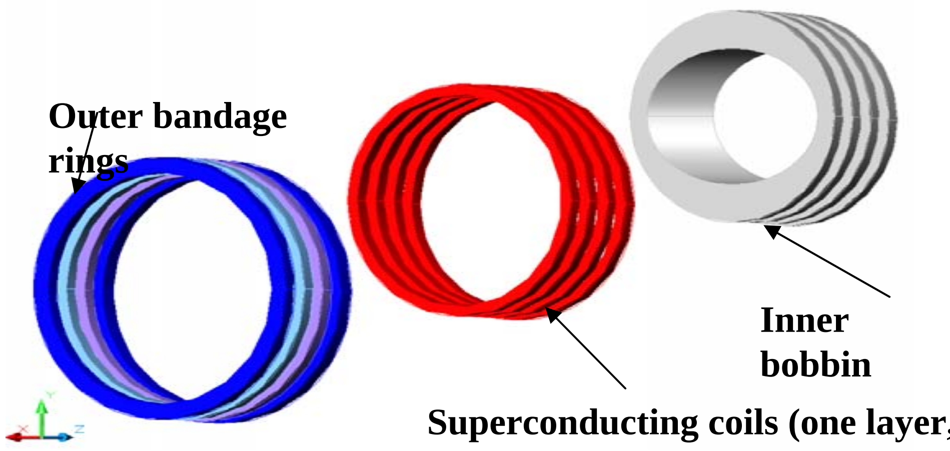
- solenoid
- matching sections

Next: engineering design

- mechanical structure
- field quality, tolerances
- cryostat
- quench protection

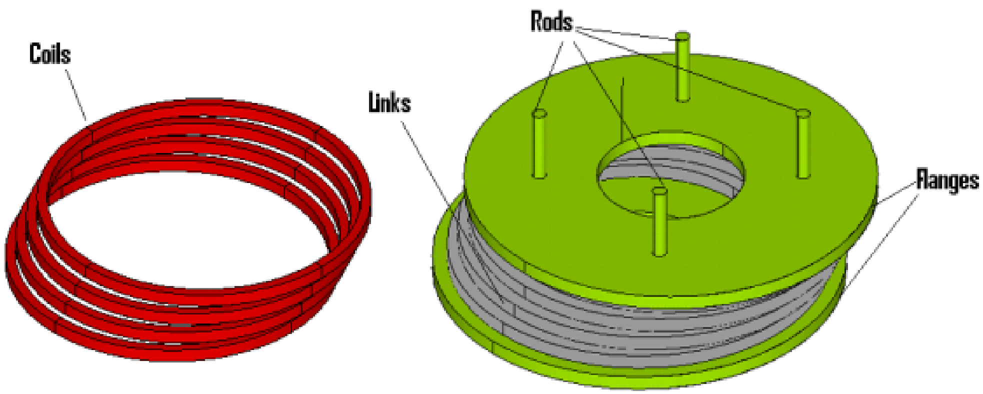
4-coil Helical Demonstration Model

- Goals:
  - validate mechanical structure and fabrication methods
  - study quench performance and margins, field quality, quench protection
- Features:
  - use existing SSC cable
  - fields and forces as in the HS for CDE
- Funded by MCTF and Muons Inc.



Parameter	Model Nominal	Model Max	MANX
Peak superconductor field	3.3 T	4.84 T	5.7 T
Current	9.6 kA	14 kA	9.6 kA
Number of turns/section	10	10	10
Coil inner diameter	420 mm	420 mm	510 mm
Lorentz force/section, Fx	70 kN	149 kN	160 kN
Lorentz force/section, Fy	12 kN	25 kN	60 kN
Lorentz force/section, Fxy	71 kN	151 kN	171 kN
Lorentz force/section, Fz	157 kN	337 kN	299 kN

4-coil model Analysis

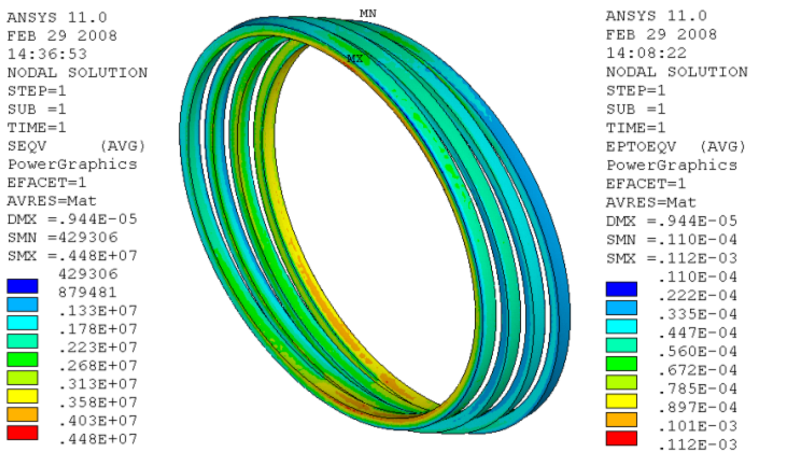


Magnetic and mechanical engineering design complete:

- 3D field distribution
- 3D stress/strain analysis in coils and mechanical structure

Von Mises Stress

Von Mises Stress

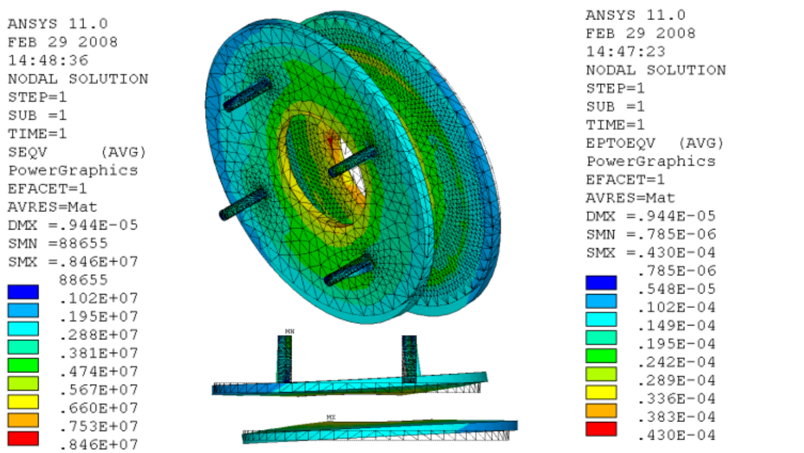


Max. Stress: 4.48*MPa*

Max. Strain: 0.0112%

Von Mises Stress

Von Mises Strain



Max. Stress: 8.46*MPa*

Max. Strain: 0.0043%

4-coil fabrication status

Parts:

- design complete
- procurement in progress

Cable:

- Extracted strand samples were tested

Practice winding complete:

- cable stability and support during hard bend winding
- coil size control

Instrumentation:

- development started

Model test:

- September 2008

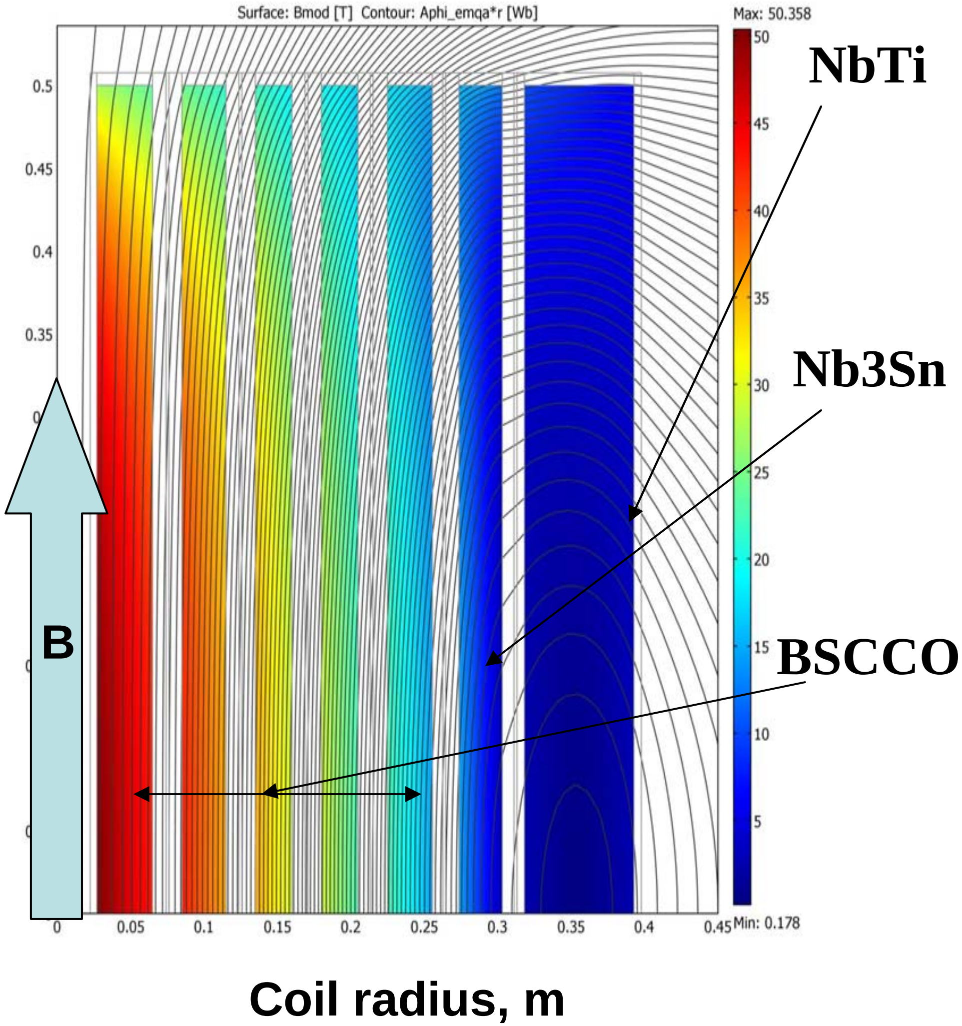
HCC R&D Plans for the next few years

- Directions of magnet R&D program are dictated by muon collaboration and MCTF goals
- Possible directions:
  - Design and build 1/4 period section of NbTi HCC incorporating RF
    - Solve RF/magnet integration issues, cryostat design, etc.
  - Design and build multi-period helical solenoid for 6-D Cooling Demonstration Experiment
    - Validate tracking
    - Better understand and optimize matching sections
    - Design magnet integrated with experiment

High Field Solenoid Development

- Used in the final muon cooling stage
- Basic Parameters
  - Inner bore diameter 50 mm
  - Length 1 meter
  - Fields 30 T or higher →
    - HTS materials
- Required R&D
  - Design Studies
    - Identify key issues
    - Determine R&D directions
  - Advances in Conductor R&D

50 T Solenoid Conceptual Design Study



Key design issues:

- superconductor Jc
- effect of field direction on Ic in case of HTS tapes
- stress management
- quench protection
- cost

Solutions:

- hybrid coil design
- coil sections

50 T Solenoid: next steps

- Build and test smaller HTS and HTS/Nb3Sn hybrid solenoid models
  - Field range: up to 20-25 T
  - HTS material: BSCCO (G1) or YBCO (G2)
  - Conductor type: round strands, cables or tapes
  - Technologies: React-&-wind or wind-&-react
- Motivate progress in HTS conductor technology
  - National Conductor Program (*see Alvin's talk*)

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MCTF Conductor Program

- Emphasis on HTS strands, tapes and cables
  - Nb3Sn and Nb3Al strand and cable R&D is supported by other programs (DOE, LARP, NIMS/FNAL/KEK, CARE, etc.)
- Collaborator as part of National HTS Program
- R&D infrastructure
  - Two Oxford Instrument Teslatron stations with 16T and 17T solenoids, and test temperatures from 1.9K to 70K
  - 42-strand cabling machine
  - Probes to measure
    - Ic of HTS strands and tapes as a function of field, temperature, and field orientation
    - transverse pressure sensitivity of strand Ic in a cable
  - 28 kA SC transformer to test cables at self-field in LHe

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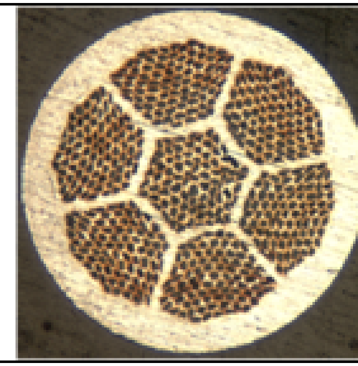
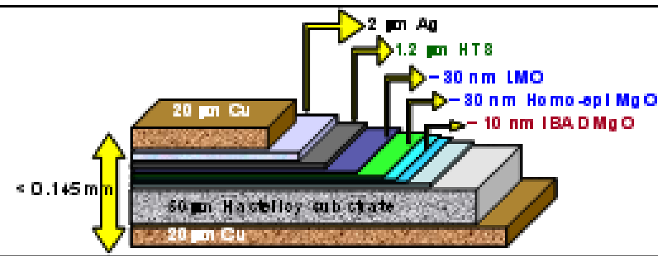
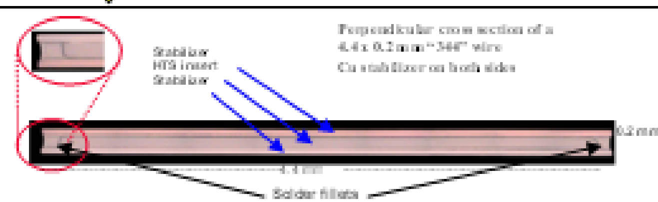
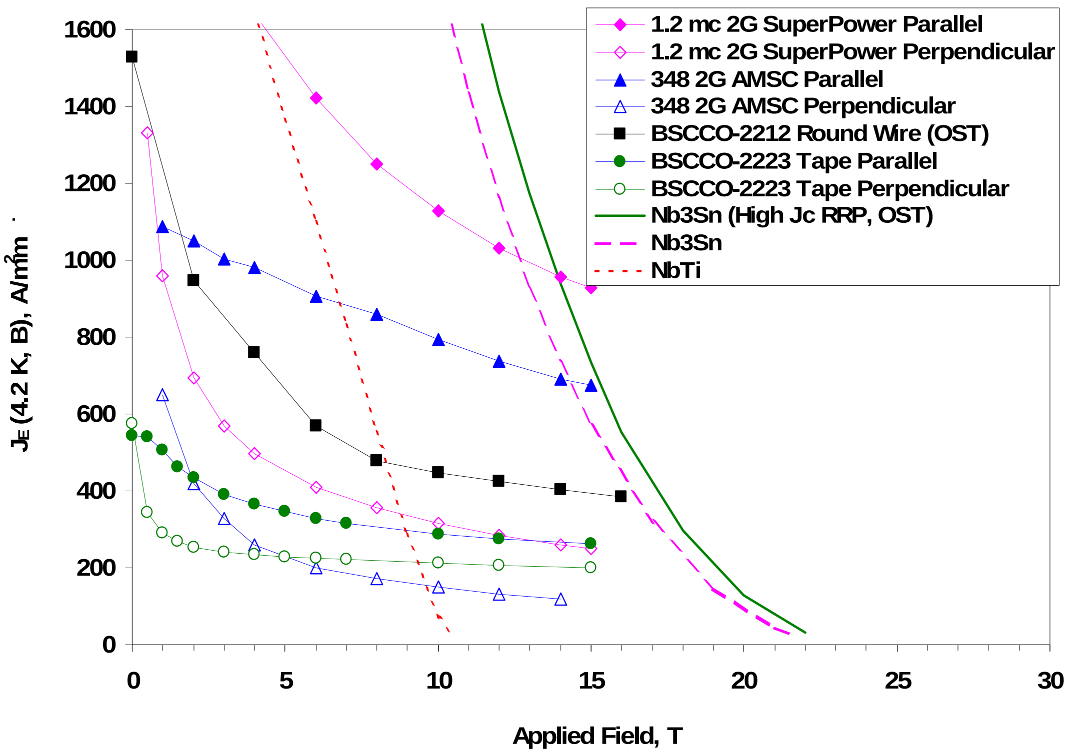
Strand and Tape Samples

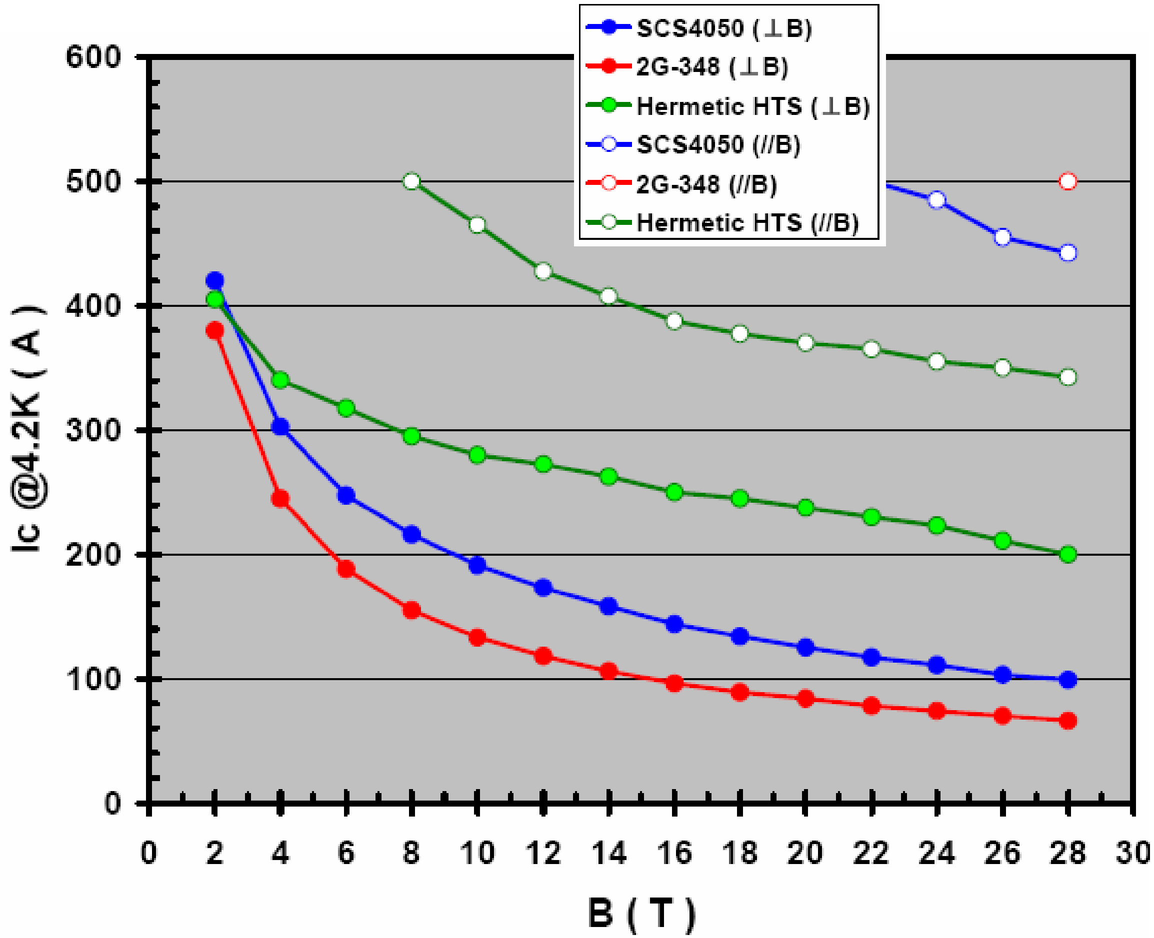
Superconductor	Conductor Type	Company	
BSCCO-2212	Round strand	Oxford SC Technologies	
BSCCO-2223	Hermetic tape	American Superconductor	
YBCO-123	SCS4050 tape	Super Power	
YBCO-123	2G-348 tape	American Superconductor	

HTS and LTS Performance at 4.2 K



- Measurement on round strands and tapes in magnetic fields up to 17T
  - Ic for tapes depends on field orientation
  - Detailed measurement of Ic angular dependence for HTS tapes at fields up to 15-16 T
  - LTS samples show better performance than HTS at low fields
- Input data for High Field HTS Solenoid design studies

High field HTS tests



- HTS tape Ic measurements at 4.2 K (with NIMS, Japan)
  - transverse fields up to 28T
  - two field orientations
- Input data for High Field HTS Solenoid design studies
  - reduce uncertainty in conductor performance at high fields

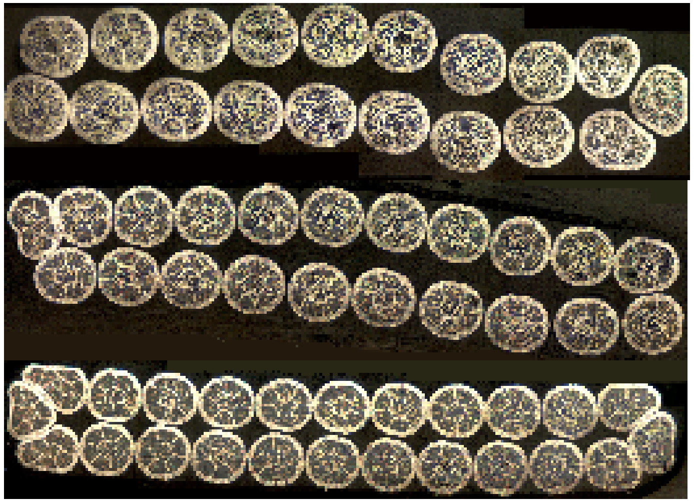
BSCCO Rutherford Cables

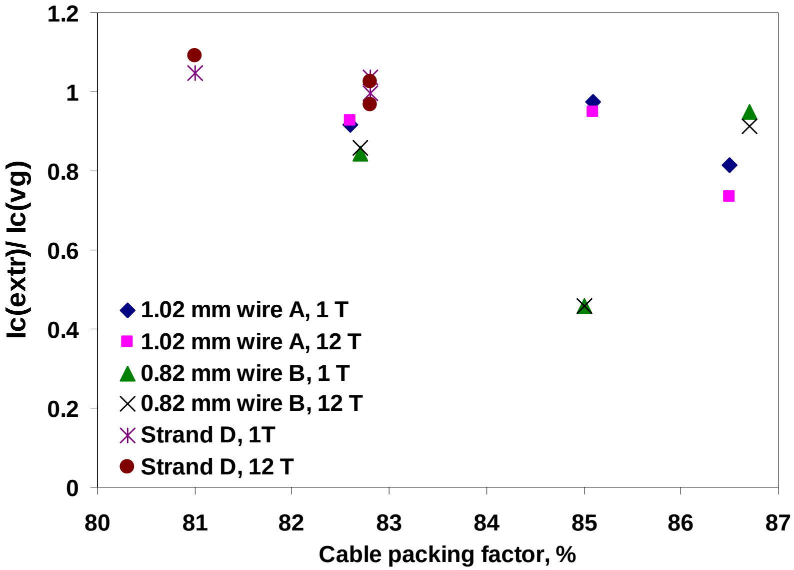
Goals:

- increase conductor Ic
- reduce magnet inductance
  - Important for magnet quench protection

Issues:

- Ic degradation after cabling
  - Determine design criteria and cabling procedures
  - low degradation at packing factors <87%
- Cable HT optimization
  - reduce Ag leaks and Ic degradation
- Transverse pressure sensitivity studies
  - determine pressure limits





Present and Future HTS R&D Plans

- HTS reaction site for strands and small coils
  - Convert existing small oven
  - Go through a safety review
- Collaborate with DOE labs, industries and Universities through National HTS Conductor program
  - Round Robin test of HTS round wire
  - Collaboration with NHFML on short sample and coil reaction cycle
  - Start small coil test program to study technology and quench issues
  - Support SBIR on HTS development

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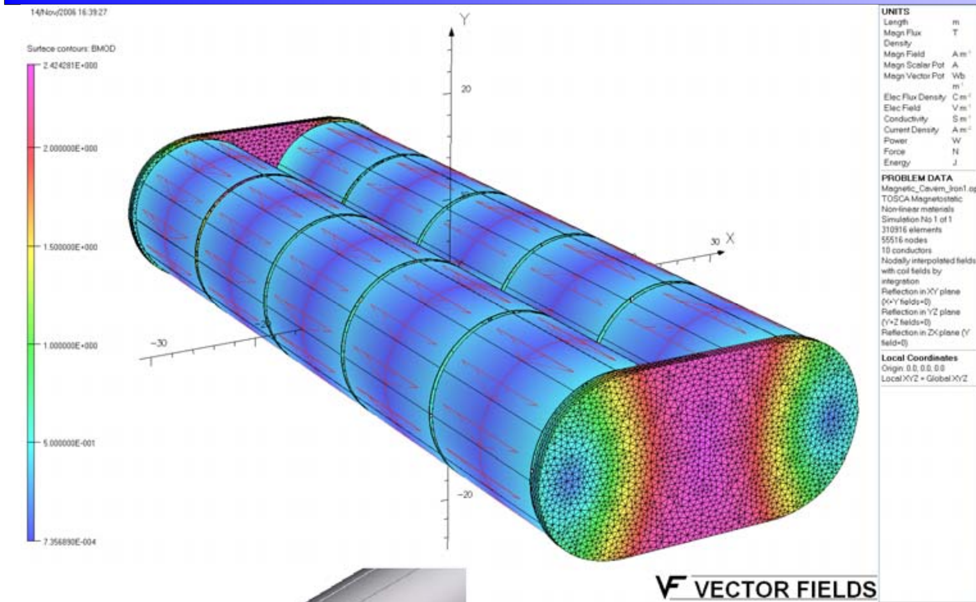
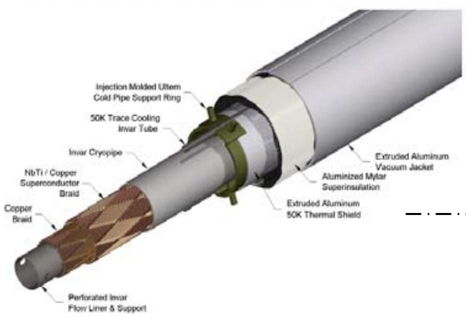
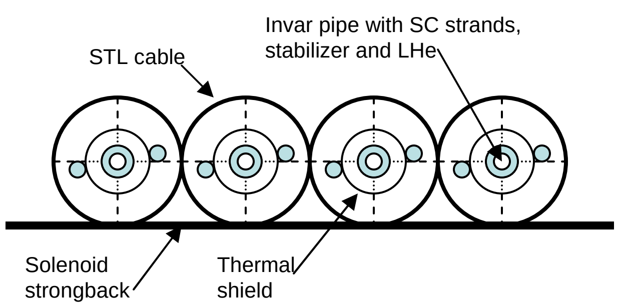
NF Detector R&D: Magnetic Cavern







- Cable based design (Fermilab)
- Features
  - 10 solenoids
  - 15-m long 15 m ID each
  - Bnom~0.5 T (50% margin)
  - 1 m iron wall, B~2.4 T
  - Good field uniformity
- Solve technical problems
- Reduce detector cost

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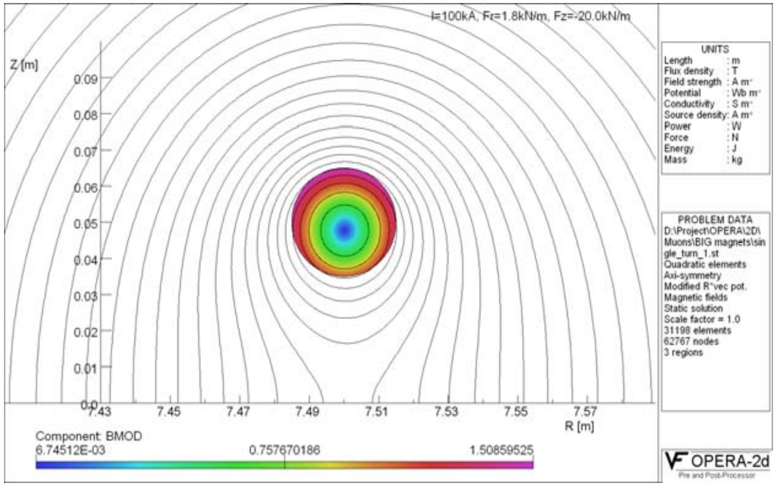
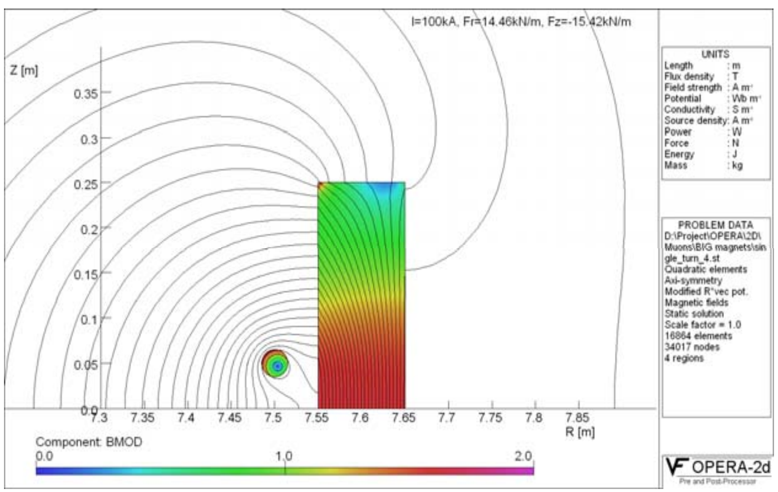
2-turn Solenoid Model (proposal)





Goals:

- Optimize cable design, thermal shield and support structure
  - Needs modification to provide long piece length (~5-7 km) and flexibility (bending diameter 15m)
- Fabricate and test ~100-m long cable prototype
- Test solenoid support structure and assembly procedure
- Test cable support structure (axial and radial mechanics)
- Measure heat leaks to LN and LHe

Unique opportunity to model a short section of the detector before fabrication.

Summary

- Magnets are one of the enabling technologies for the Muon Collider/Neutrino Factory
- The development of practical muon collider magnets is a long term investment
- MCTF Magnet program has already created a strong foundation and has made progress in all key directions
- Important on going and near term activities
  - Support the National HTS R&D program
  - Design and possibly build relevant demonstration magnets
    - NbTi Helical Solenoids without and with RF
    - Moderate field solenoids and very high field solenoids in support of Muon Cooling Experiments
  - Continue the conceptual design studies of collider ring, IR and detector magnets
- It is critical for the community to increase the support of advanced magnet and HTS R&D
  - i.e. stable funding and manpower resources