Magnet R&D for Muon Colliders at Fermilab

Fermilab Muon Collider Task Force

- Established in Summer 2006 from Lab Director mandate
- MCTF charge
  - "….develop a plan for an advanced R&D program aimed at the technologies required to support the long term prospects of a Muon Collider.."
- Targeted magnet technologies
  - Magnets for 6-D cooling channel
  - Very high field solenoids for final stages of cooling
  - Longer term goals for collider ring and IR magnet development

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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

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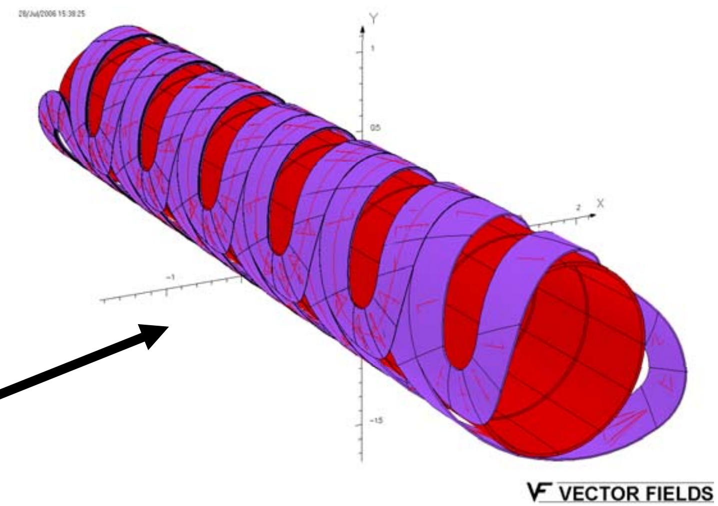
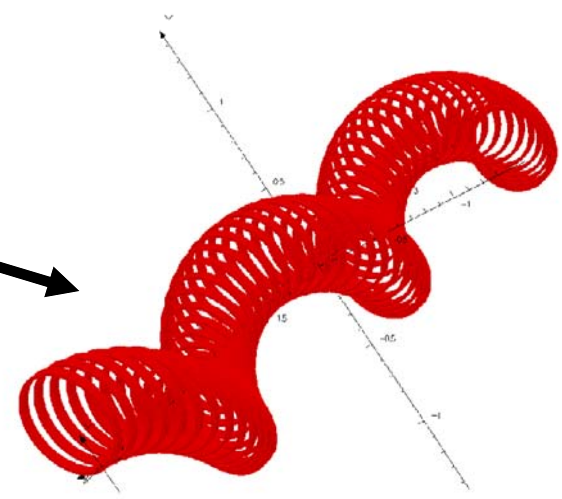
HCC Magnets

- HCC Concept from Y. Debenev and R. Johnson
- Solenoid, with superimposed helical quad/dipole filled with low Z material can reduce 6D emittance



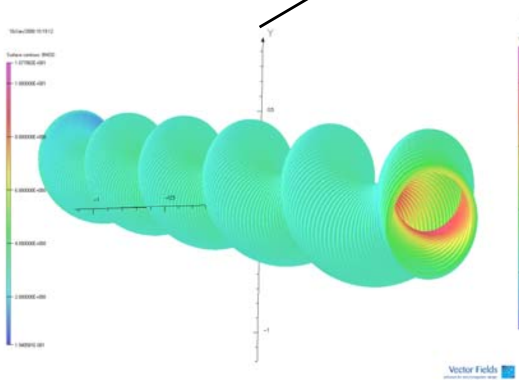
- Vl. Kashikhin developed alternate magnet design: dipole/quad field generated by solenoid rings offset transversely

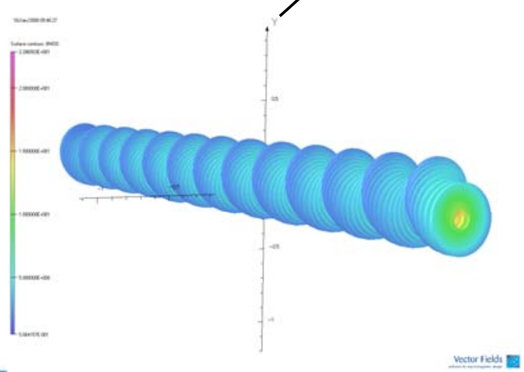


- Dipole/quad fields are very dependent of coil geometry

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





Vl. Kashikhin, S. Zlobin with Muons Inc.

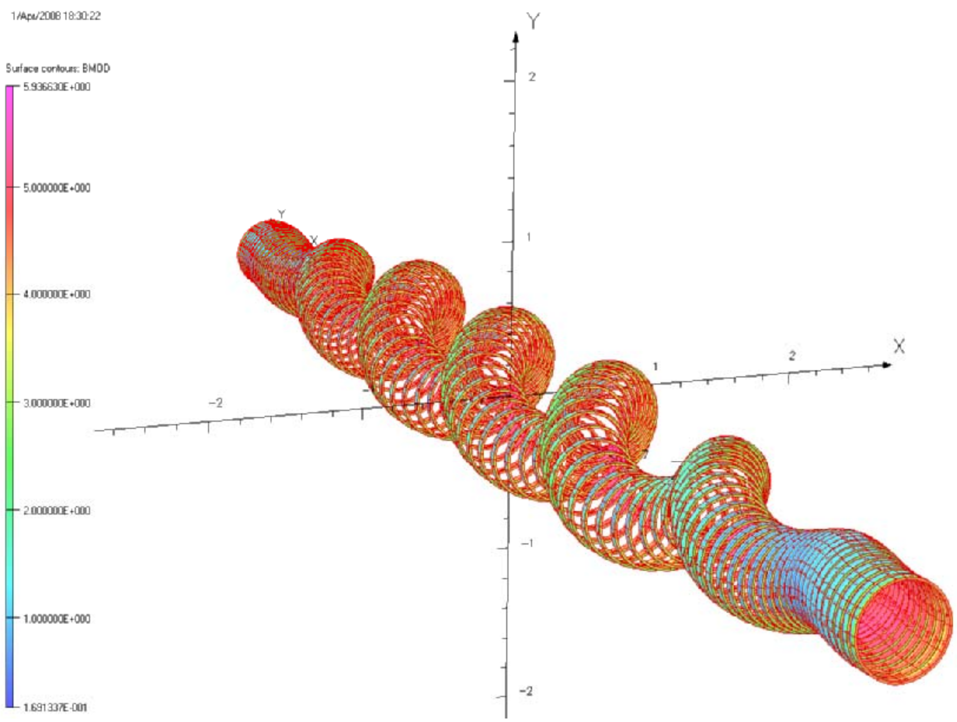
- Multi stage HCC study
  - –Wide range of fields, helical periods, apertures
  - –Straight solenoid concept does not work for high-field/small-aperture sections
  - –Field tuning more complicated at high fields
  - –NbTi, Nb3Sn/Nb3Al and probably HTS in final stage
- Studies will continue

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

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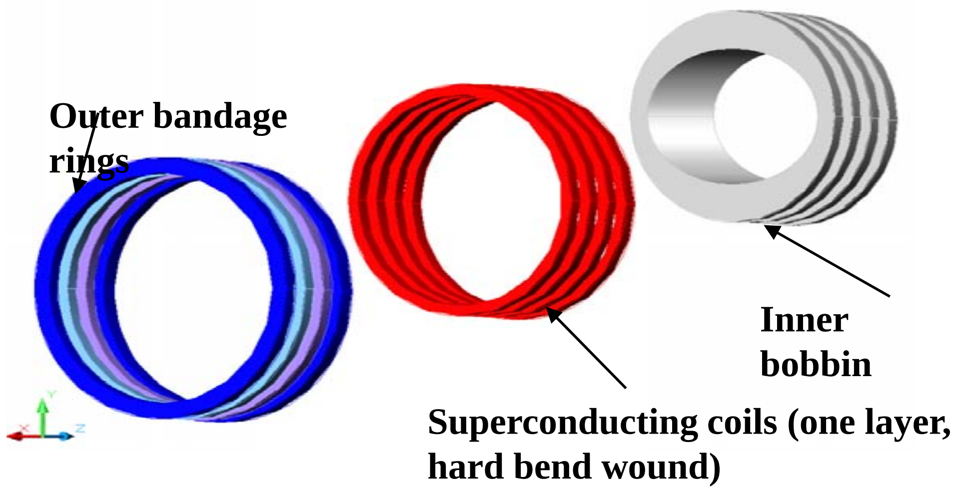
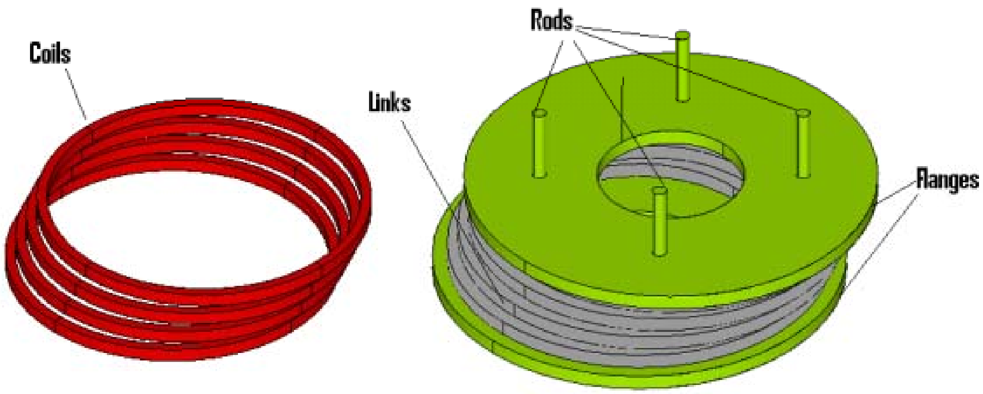
4-coil Helical Demonstration Model

- 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

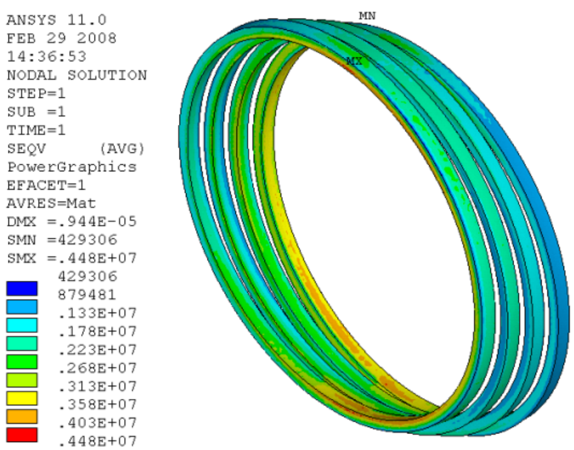
4-coil model Analysis



Magnetic and mechanical engineering design complete:

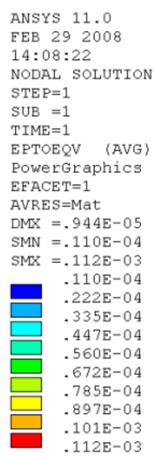
- 3D field distribution
- 3D stress/strain analysis in coils and mechanical structure

Von Mises Stress



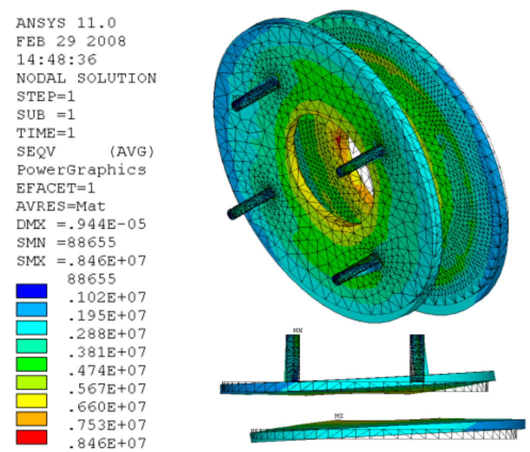
Max. Stress: 4.48*MPa*

Von Mises Stress



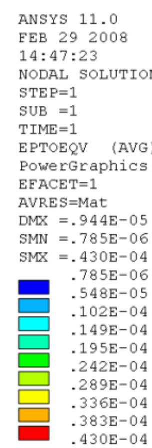
Max. Strain: 0.0112%

Von Mises Stress



Max. Stress: 8.46*MPa*

Von Mises Strain



Max. Strain: 0.0043%

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4-coil fabrication status

Sasha Makarov, Vl. Kashikin, M. Yu

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

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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

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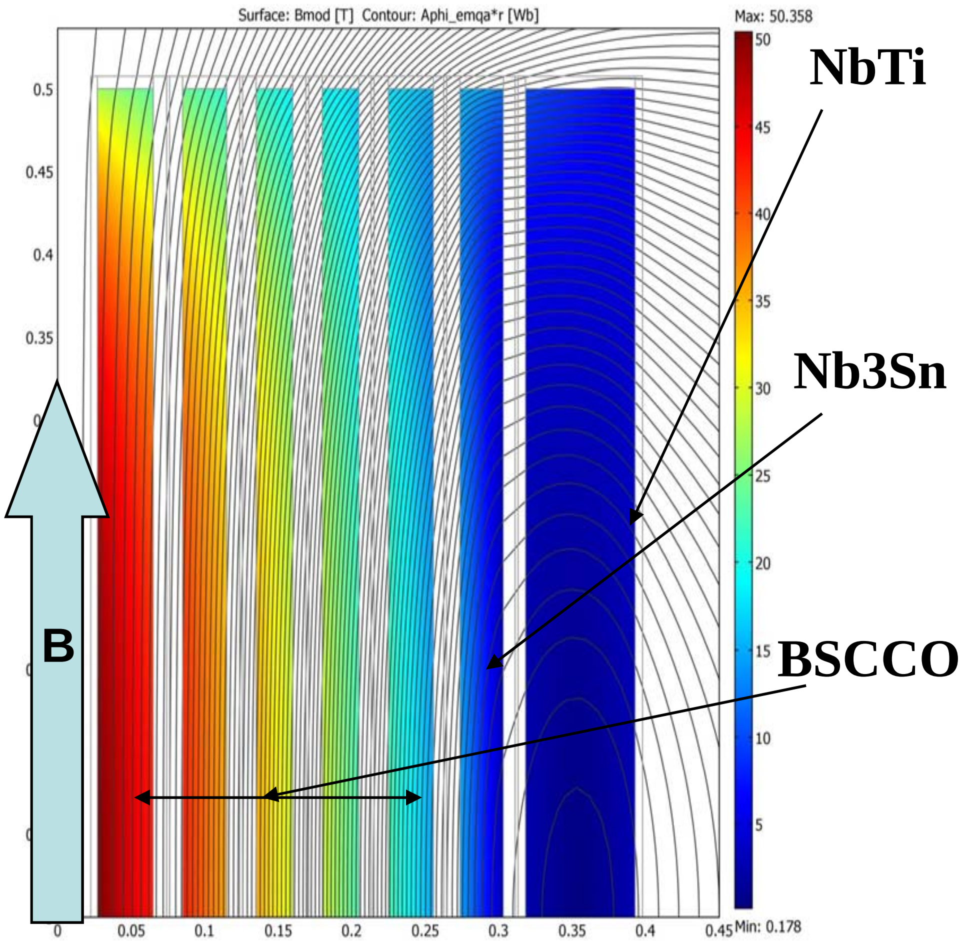
50 T Solenoid Conceptual Design Study



Coil radius, m

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

Vadim Kashikhin presented at MT20

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
- Conductor Development
  - National Conductor Program in HTS
  - Base program support

National HTS Program

- "…to develop the magnet technology necessary for the construction of magnets with fields > 25 T using HTS"
- Participating institutions: BNL, FNAL, LANL, LBNL, NHFML, NIST…Plus universities
- Issues for Magnets
  - Leakage, Connectivity, Dependence of Jc on angle wrt B., Conductor insulation, Containing the forces and controlling, strain, Quench protection, W&R vs. R&W, Cabling, Radiation resistance.
- Near term focus on round Bi 2212 wire
- Status:
  - Technical Board with reps from each institution
  - Groups formed to study testing, insulation…
  - Modest budget for FY08, developing proposal for FY09

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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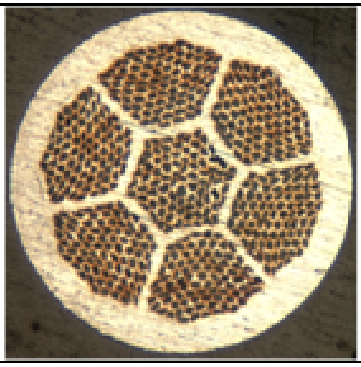
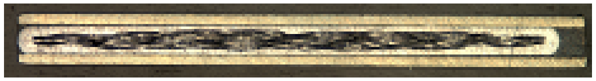
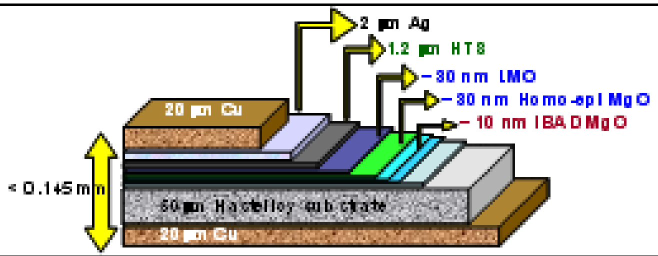
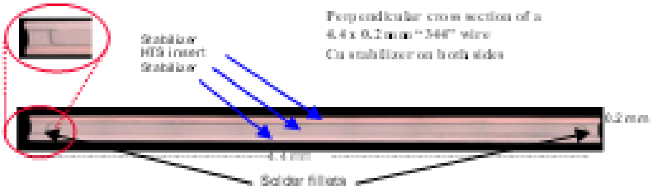
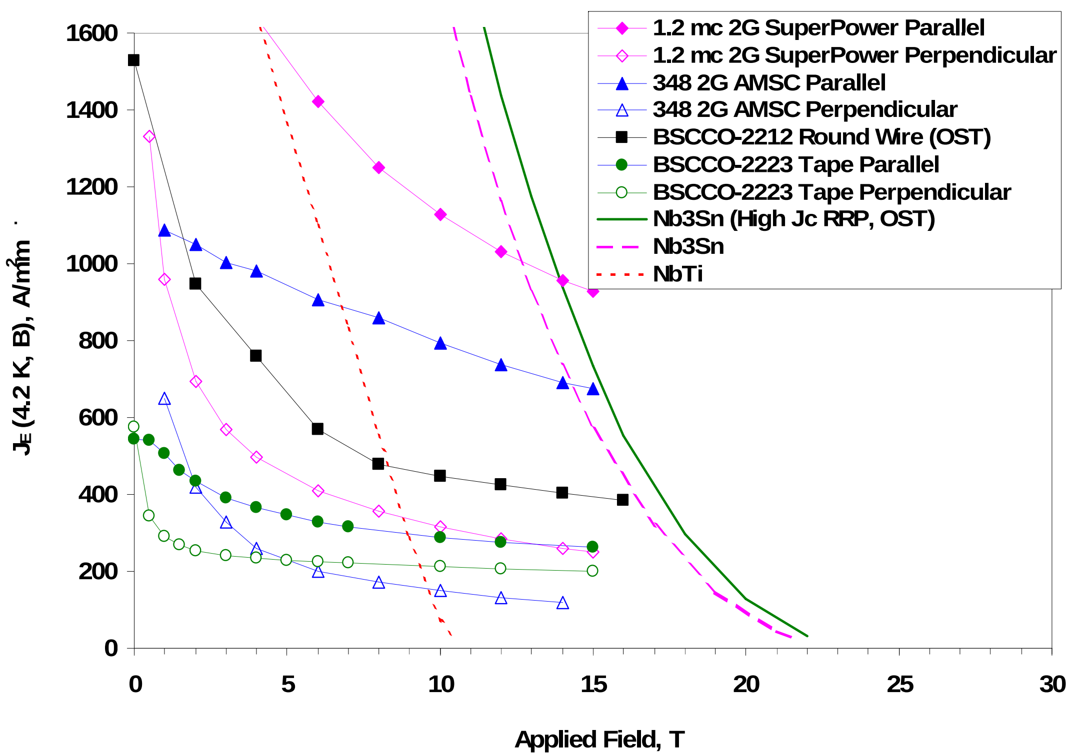
Strand and Tape Samples

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



E. Barzi, LTSW 2007, Oct. 29-31, 2007, South Lake Tahoe, CA

- 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

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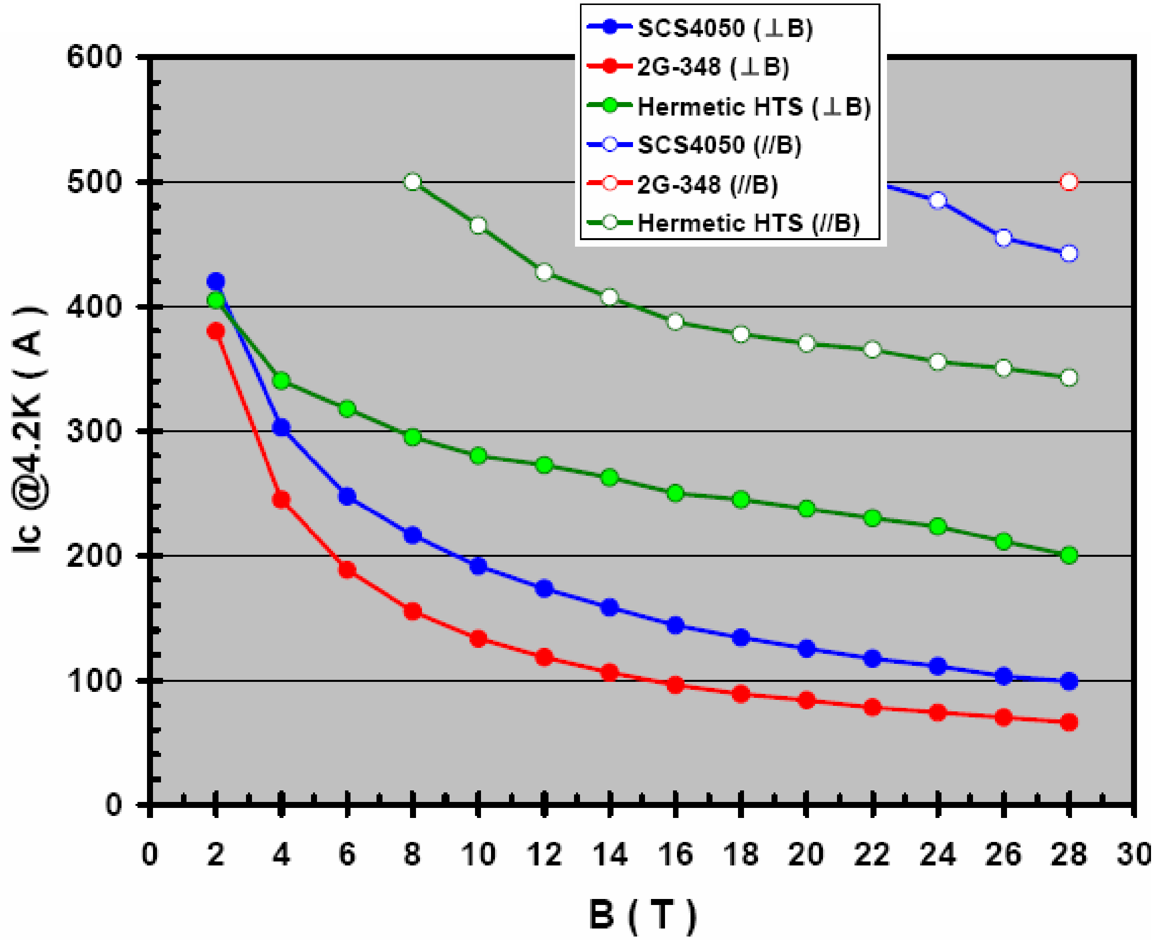
High field HTS tests



- 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

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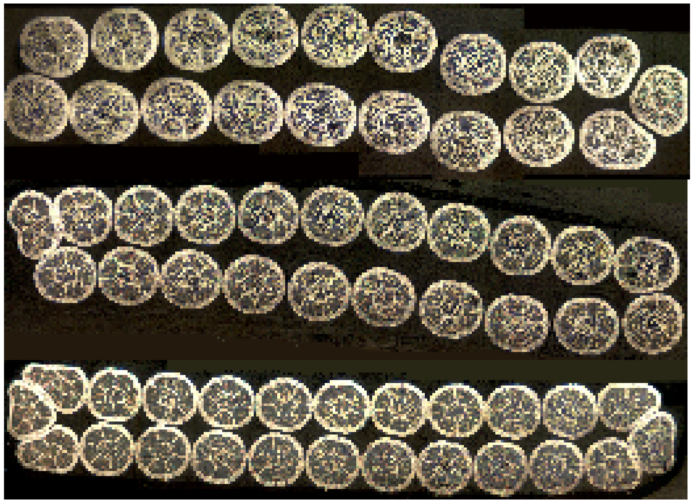
BSCCO Rutherford Cables

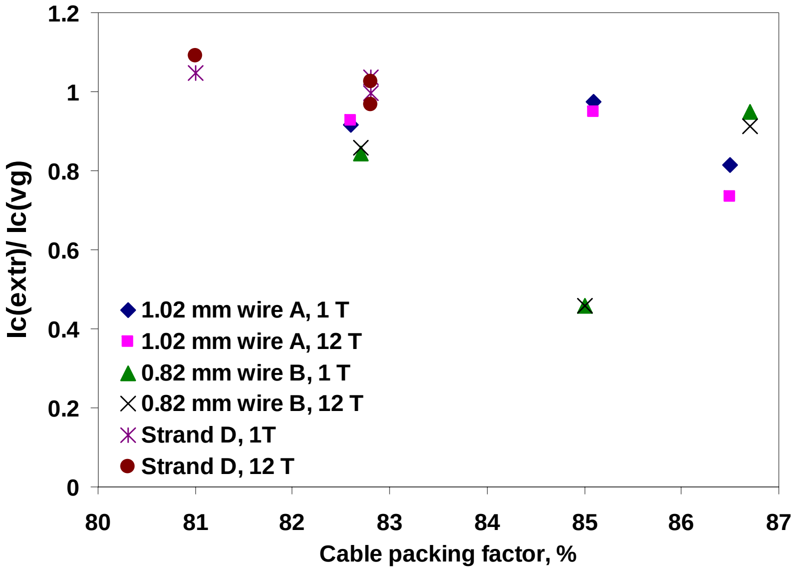
Goals:

- 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





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Present and Future HTS R&D Plans

- HTS reaction site for strands and small coils
  - Convert existing small oven
    - Preliminary design complete
  - Go through a safety review (O_2 ES&H)
    - Seeking advice from national labs that with working ovens (that have gone through the review process)
- Continue to develop probes for testing HTS in Teslatron
  - Designing Tensile strain probe
- Working with American Superconductor to build small YBCO coils suitable for Teslatron. Quench performance function of temperature and field

Present and Future HTS R&D Plans

- 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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Summary

- Magnets are one of the enabling technologies for the Muon Collider
- The development of practical muon collider magnets is seen as a long term investment
- Fermilab 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