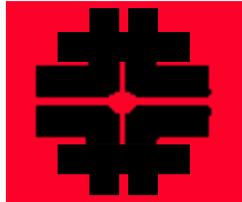
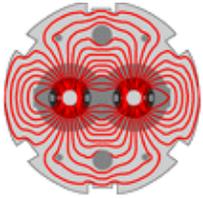


LARP

LARP Magnet R&D

S. Gourlay for the LARP Magnet Collaboration

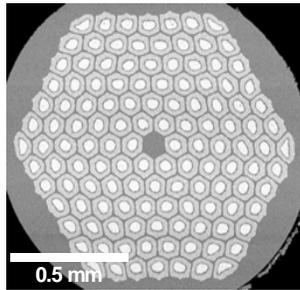




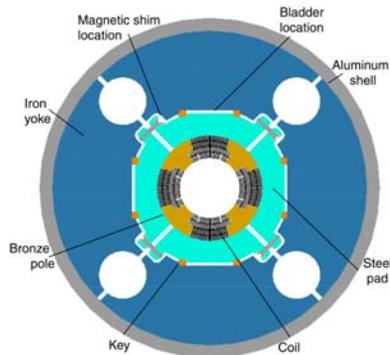
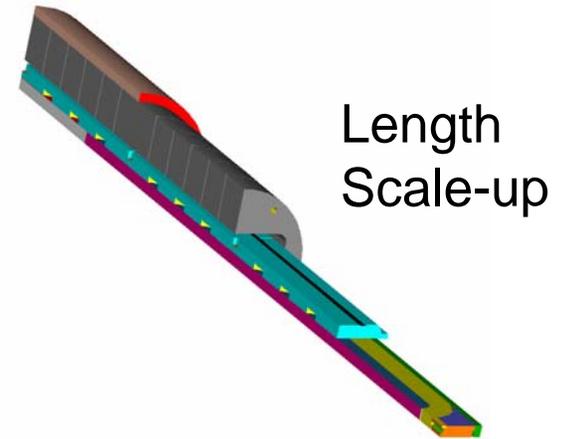
LARP

US LARP Magnet Program

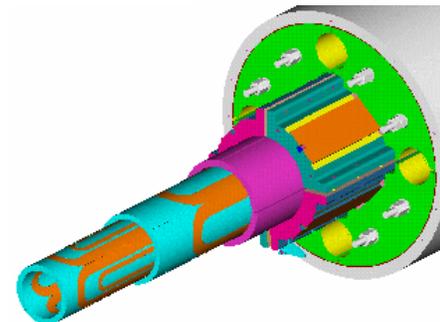
Large aperture, Nb₃Sn Quadrupoles for LHC Upgrade

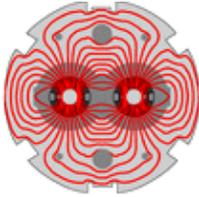


High Performance
Conductor Development



90 mm
> 250 T/m





LARP

Magnet Program Goals

Provide options for future upgrades of the LHC Interaction Regions

- **Demonstrate by 2009 that Nb₃Sn magnets are a viable choice for an LHC IR upgrade**

— Focus on major issues: consistency, bore/gradient (field) and length

1. **Predictable and reproducible performance**

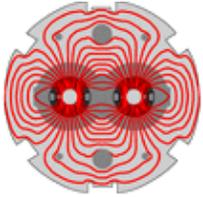
TQ models (1 m, 90 mm aperture, $G_{\text{nom}} > 200$ T/m, $B_{\text{coil}} > 12$ T)

2. **Long magnet fabrication**

LQ models (4 m, 90 mm aperture, $G_{\text{nom}} > 200$ T/m, $B_{\text{coil}} > 12$ T)

3. **High gradient in large aperture**

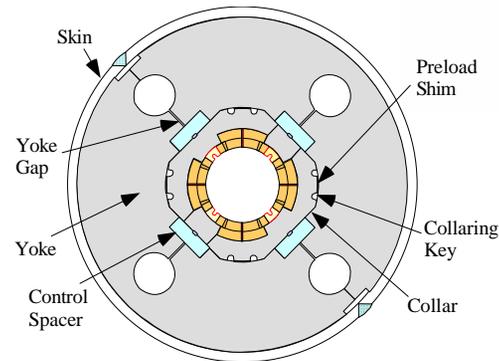
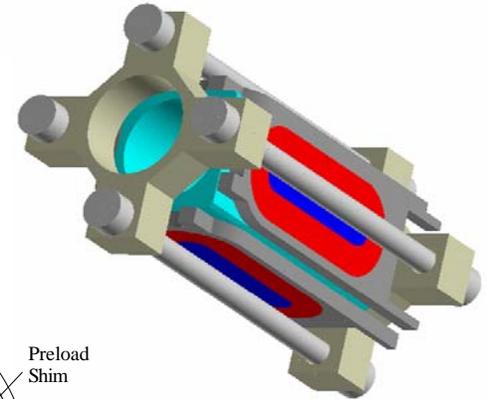
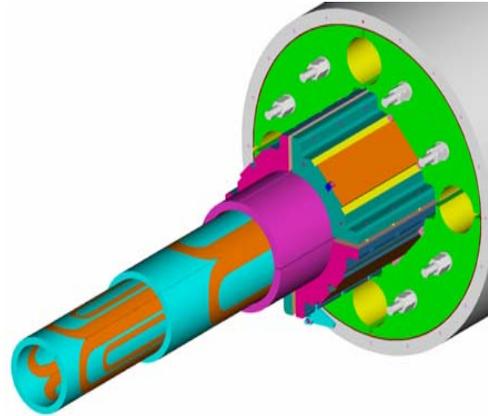
HQ models (1 m, 90 mm aperture, $G_{\text{nom}} > 250$ T/m, $B_{\text{coil}} > 15$ T)



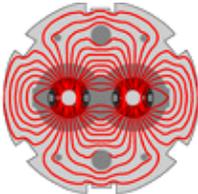
LARP

Goal #1 Predictable and Reproducible Performance

- **Sub-scale Quadrupoles (SQ)**
 - Conductor evaluation
 - Analysis validation
- **Technology Quadrupoles (TQ)**
 - 90 mm aperture
 - Gradient > 200 T/m
 - Explore alternate structures using “identical” conductor
 - Basis for scale-up



Goal #2 Long Magnet Fabrication



LARP

- **Long Racetrack**

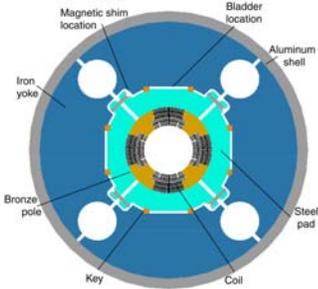
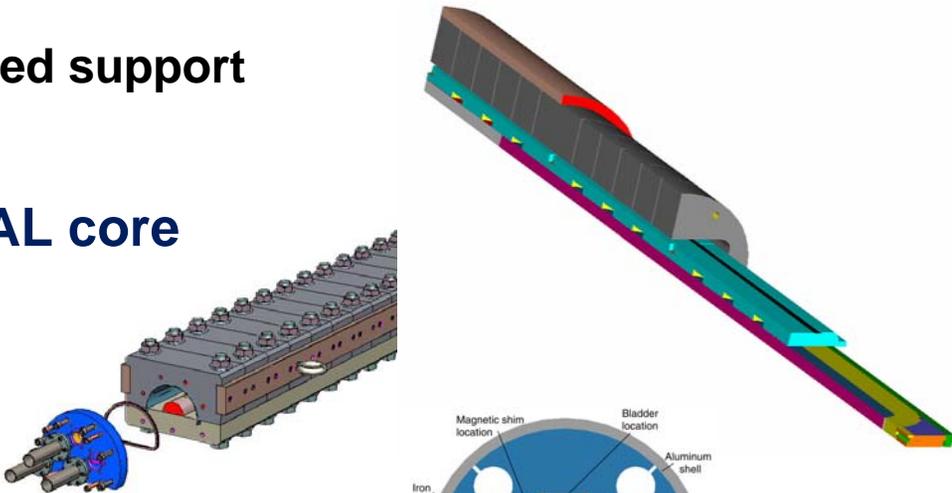
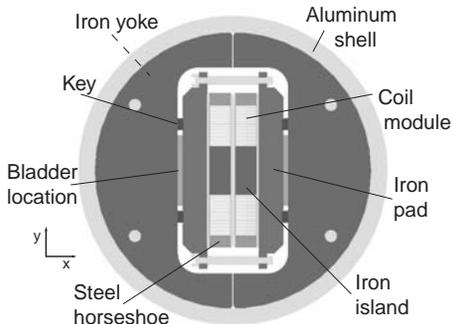
- Coil fabrication scale-up based on well-understood sub-scale coils
- Explore scale-up of shell-based support structure

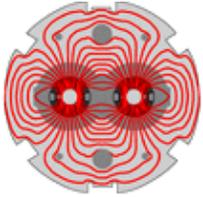
- **Mirror dipole scale-up via FNAL core program**

Followed by . . .

- **Long quadrupole (LQ)**

- 3.6 m quadrupole based on TQ cross-section





LARP

Goal #3 High Gradient in a Large Aperture

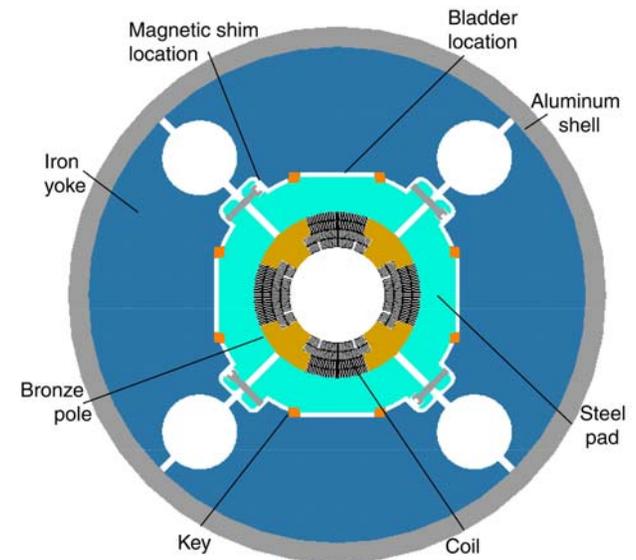
- **High Gradient Quadrupole (HQ)**

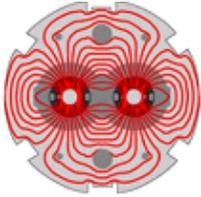
— **Explore ultimate performance**

- **Increase peak field on the coil to ~ 15 T**
- **Precursor to larger aperture**

Subject of Design Studies

4-layer: $G=280-310$ T/m





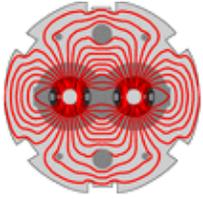
Target Program (Phase I)

LARP

Integrated, 3-lab collaboration - **BNL, FNAL, LBNL**

Model Magnets		Type	Length (m)	Gradient (T/m)	Aperture (mm)	FY05	FY06	FY07	FY08	FY09
Series Description										
TQ	Technology Quad	Cos-2theta	1	> 200	90		$3_N + 1_R$	$2_N + 1_R$		
LQ	Long Quad	Cos-2theta	4	> 200	90				1_N	1_N
HQ	High Gradient Quad	Cos-2theta	1	> 250	90					2_N
Supporting R&D		Type	Length (m)	Peak Field (T)	Aperture (mm)	FY05	FY06	FY07	FY08	FY09
Series Description										
SQ	Sub-scale	block	0.3	10 – 11	110	$1_N + 1_R$	$1_N + 1_R$	$1_N + 1_R$	1_N	
SR	Short Racetrack	block	0.3	10 – 12	N/A		1_N	1_N	1_N	
LR	Long Racetrack	block	4	10 - 12	N/A			2_N		
N = New Magnet										
R = Revised Magnet using existing coils										

Phase II – Focused prototype development
2009 - 2012



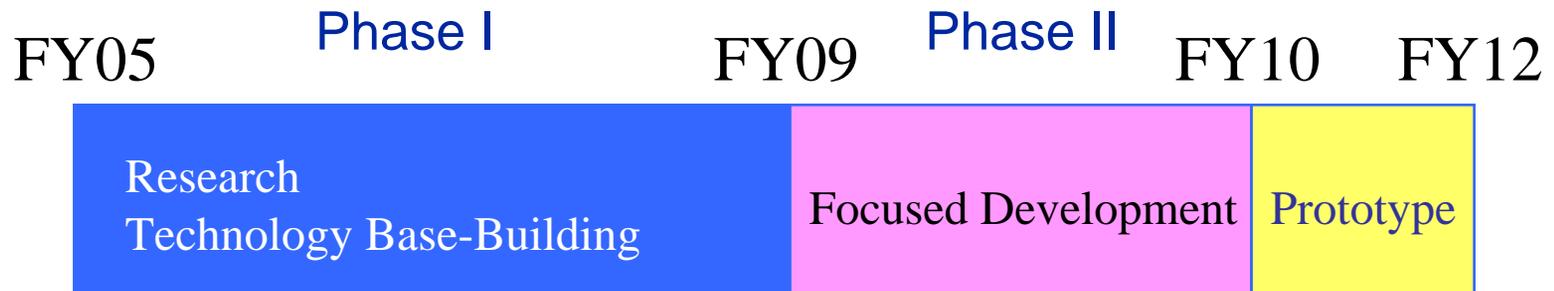
LARP

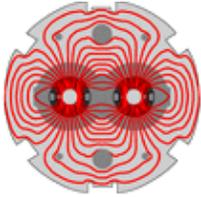
Program Elements and Timeline

Phase I - initial focus on developing technology base

- **Start aggressively**
 - evaluate status and the challenge ahead
 - But . . . be conservative and focused enough to meet LHC goals.

Phase II – focused development of IR quad





LARP

Program Implementation

- **Model Magnet R&D**

- Technology Quadrupoles (TQ)
- Support structure development
- Reproducibility
 - **Field quality not an initial priority**

- **Materials**

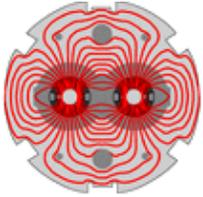
- Strand and cable evaluation
- Provide engineering material
- Long-term R&D

- **Supporting R&D**

- Long Racetrack Coils (LR)
 - **Fast start, early feedback**
- Fabrication techniques
- Analysis validation (small models)
- Rad-hard materials
- Test coordination/standardization

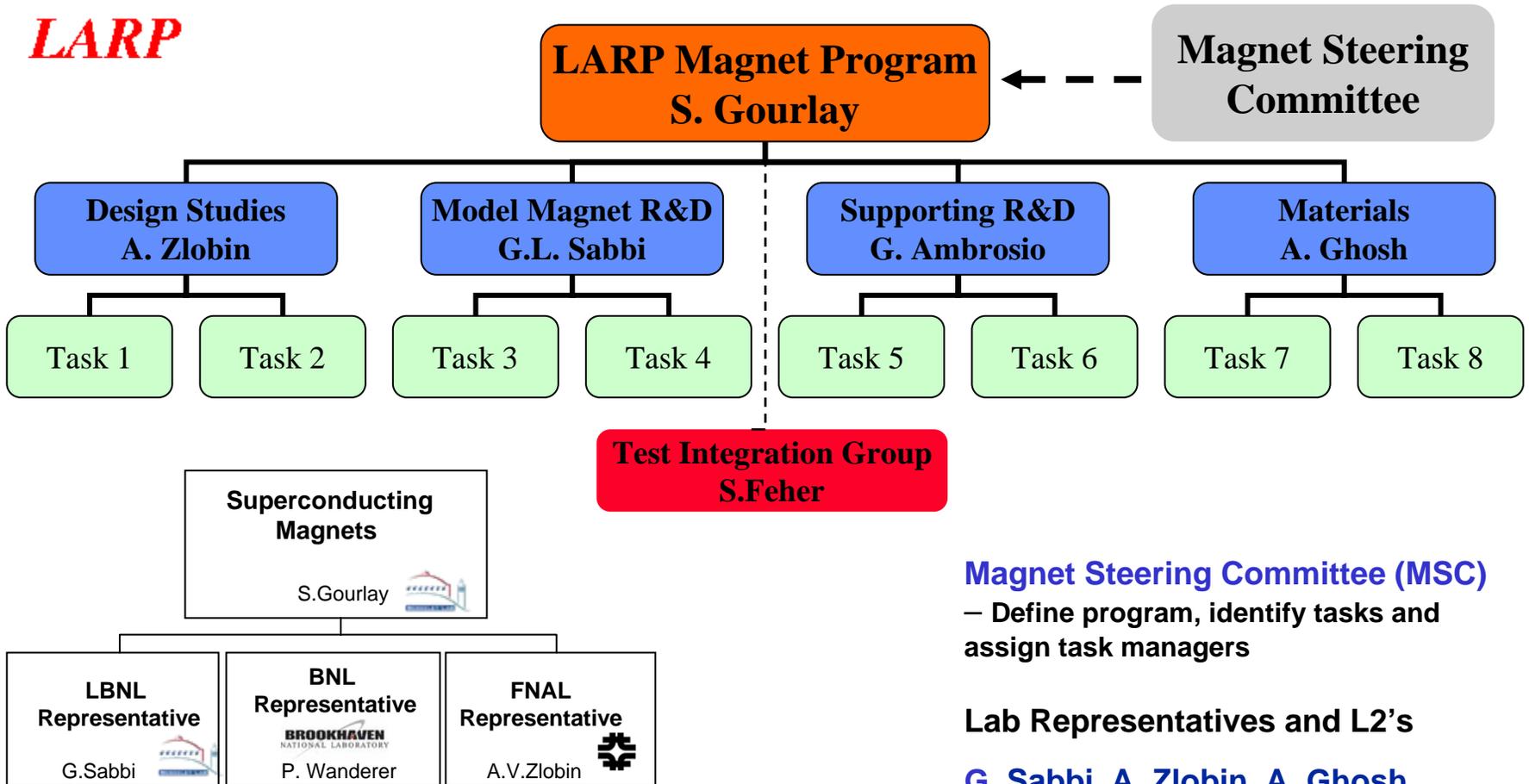
- **Design Studies**

- Emphasize support of TQ's
- Diversity to guide program and provide options



LARP

Management Structure

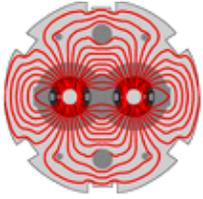


Magnet Steering Committee (MSC)
– Define program, identify tasks and assign task managers

Lab Representatives and L2's

**G. Sabbi, A. Zlobin, A. Ghosh,
G. Ambrosio, S. Gourlay,
P. Wanderer, J. Kerby**

Lab representatives oversee tasks/sub-tasks at host laboratory

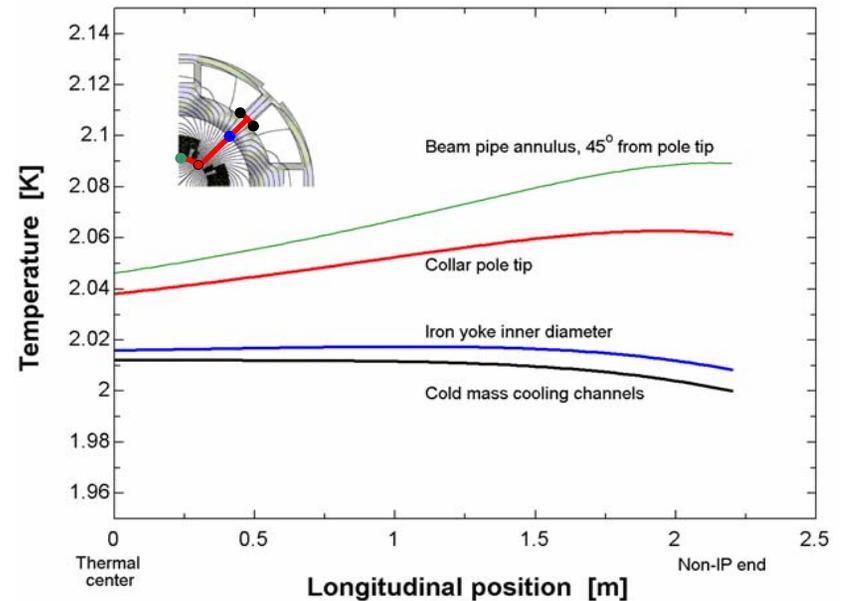
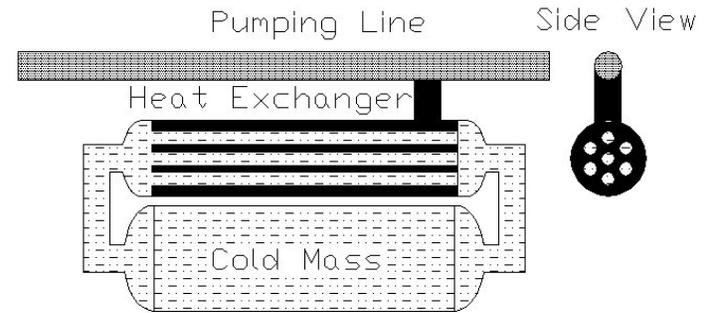


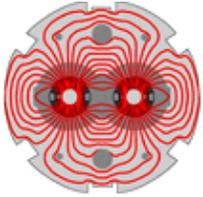
LARP

FY06 Accomplishments and Status

Design Studies

- **IR Cryo Studies**
 - Temperature profiles
 - Design parameters
 - Quench Protection studies
 - Radiation Heat Deposition
- **IR Magnets**
 - HQ conceptual design
 - LQ conceptual design
 - IR magnet study

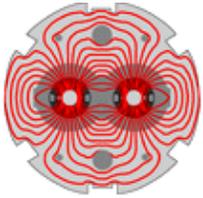




LARP

Design Studies

WBS				BNL	FNAL	LBL
2.1	Design Studies	Zlobin	416	99	205	112
2.1.4	IR Magnets					
2.1.4.1	HQ conceptual design	Sabbi	101		39	62
2.1.4.2	LQ conceptual design	Ambrosio	130	29	51	50
2.1.4.3	IR magnet study	Wanderer	69	48	21	
2.1.3	IR Cryogenics					
2.1.3.2	Inner triplet cryo & heat transfer	Rabehl	71	22	49	
2.1.3.3	Radiation heat deposition	Mokhov	45		45	



FY06 Accomplishments and Status

LARP

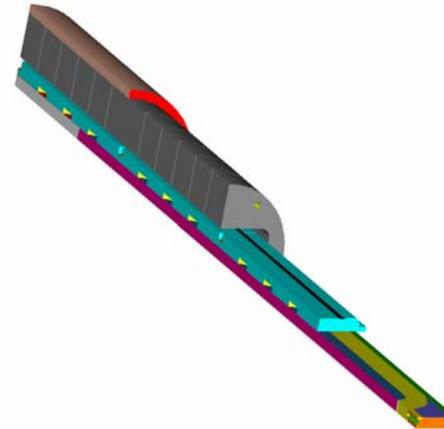
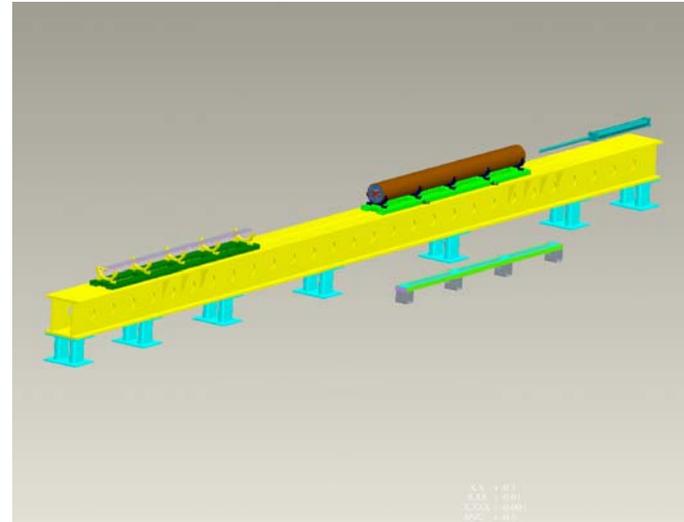
Supporting R&D

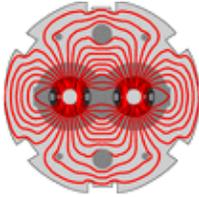
Subscale Models

- SQ02
 - Complete

Long Magnet Development

- Racetrack coil fab and test
 - Tech x-fer – SR01
- Racetrack support structure

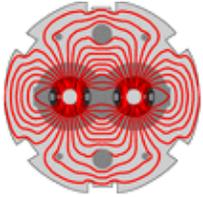




LARP

Supporting R&D

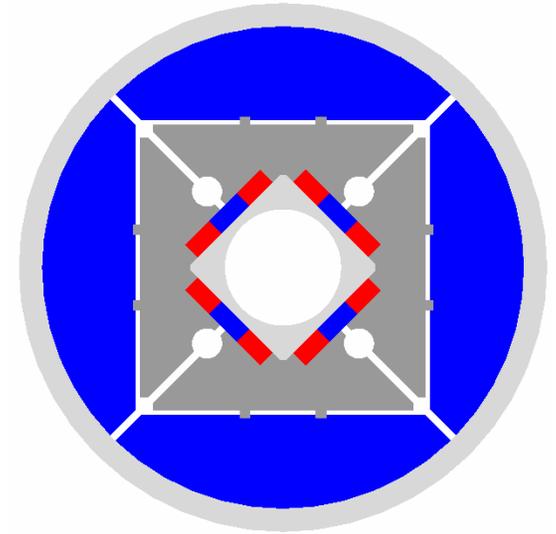
WBS				BNL	FNAL	LBNL
2.3	Supporting R&D	Ambrosio	1982	1419	82	481
2.3.1	Subscale models					
2.3.1.2	Small Quad SQ02 fab & test	Ferracin	155		23	132
2.3.2	Long Magnet Development					
2.3.2.2	Racterack coil fab & test	Schmalzle	1515	1399	24	92
2.3.2.3	Racetrack supporting structure	Ferracin	222			222
2.3.3	Test integration					
2.3.3.1	Testing	Feher	90	20	35	35



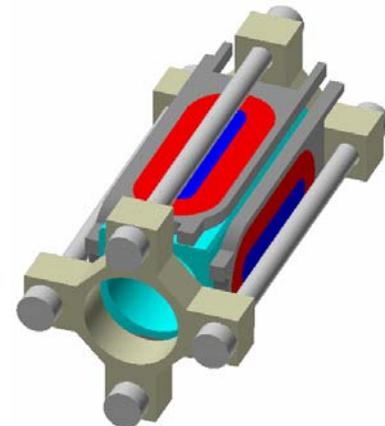
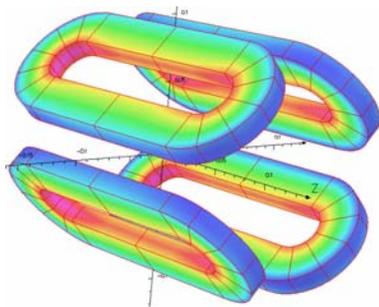
SQ02 Magnet Design Support Structure

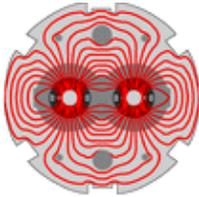
LARP

- **Stainless steel pads**
- **Iron yokes**
- **Aluminum shell**
- **Axial support: 4 Al rods and ss end plate**
- **Strain gauges on shell and rods**
- **Peak field in the innermost turn**



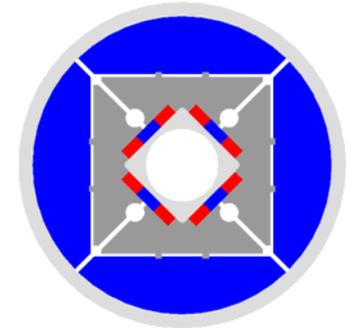
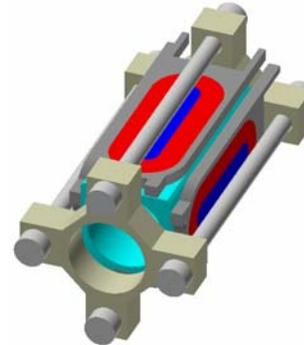
MJR – same as used in the TQs



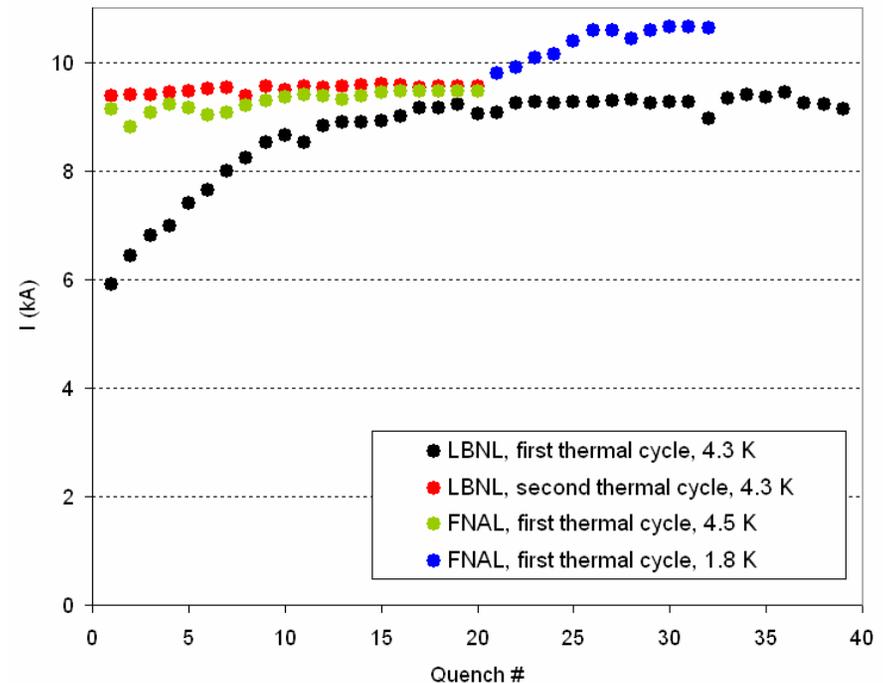


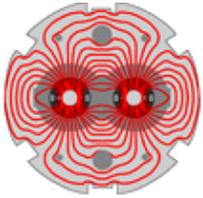
LARP

SQ02



- Tested at LBNL in 10/05
 - First thermal cycle (4.3 K)
 - 1st quench: 60 % I_{ss}
 - 90 % in 13 quenches
 - $I_{max} = 95 \% I_{ss}$
 - Second thermal cycle (4.3 K)
 - 1st quench: 95 % I_{ss}
 - $I_{max} = 97 \% I_{ss}$
 - $I_{max} = 9.6 \text{ kA}$
 - $B_{max} = 10.7 \text{ T}$
 - $G_{max} = 81 \text{ T/m}$
- Retested at FNAL at higher axial pre-stress in 03/06
 - $I_{max} = 10.6 \text{ kA}$ (1.8 K)

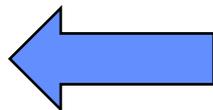




Long Racetrack Coils (LR)

LARP

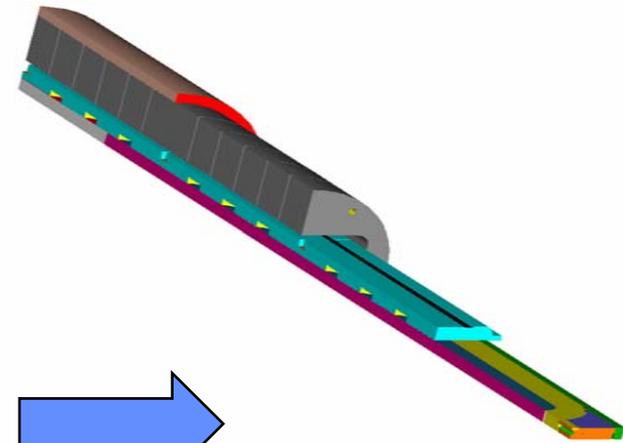
- **Main Objective:**
 - Design, fabricate and test long racetrack, wind and react coils
 - Use same or similar methods as LQ magnets
- **Features:**
 - Double layer coils
 - Coil length = 3.6M (fit in vertical dewar)
 - 40 turns total (20 per layer)
 - Test as pair of double layer coils

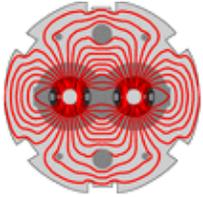


1 foot to 4 meters



Shell-based
support structure

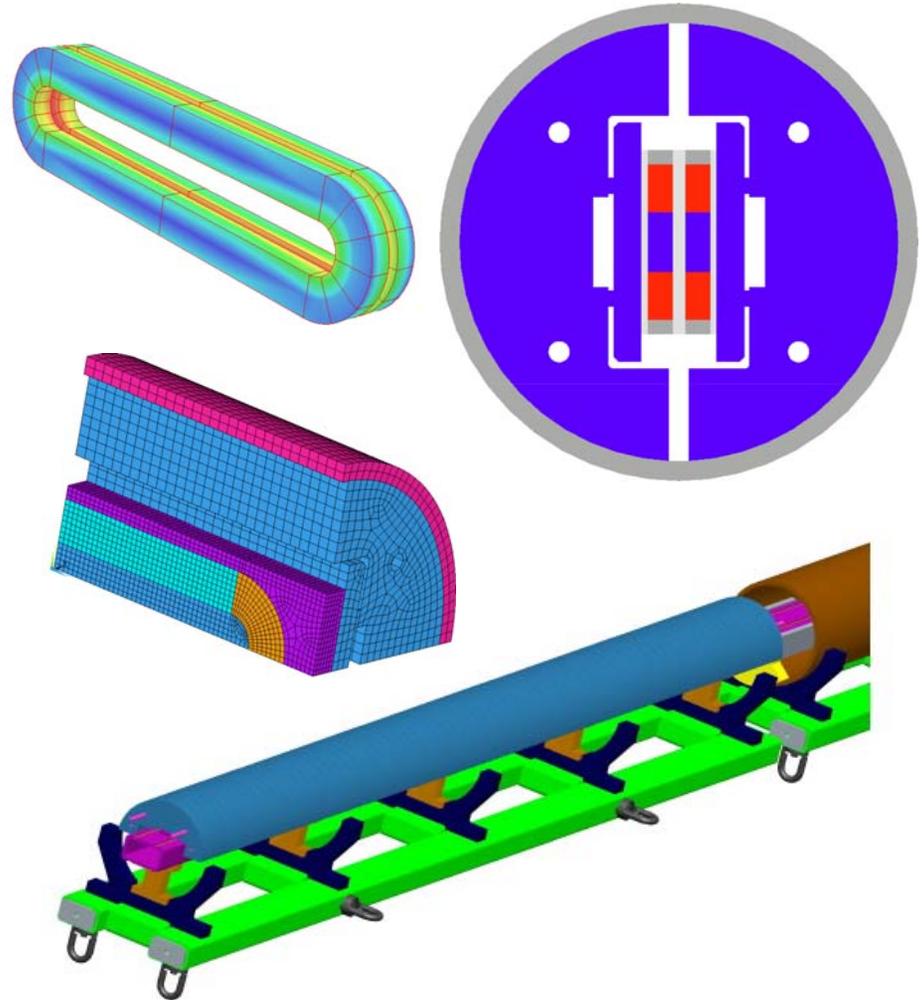




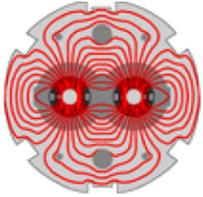
LARP

Long Racetrack Supporting Structure

- **Task**
 - Design and test of a 4 m long supporting structure for a sub-scale racetrack magnet
- **Design and analysis completed**
- **Parts procured**
- **Assembly and test with dummy coils expected in May-June 2006**



EXPLD STATE: INSTALL1(+)



LARP

FY06 Accomplishments and Status

Materials

Strand

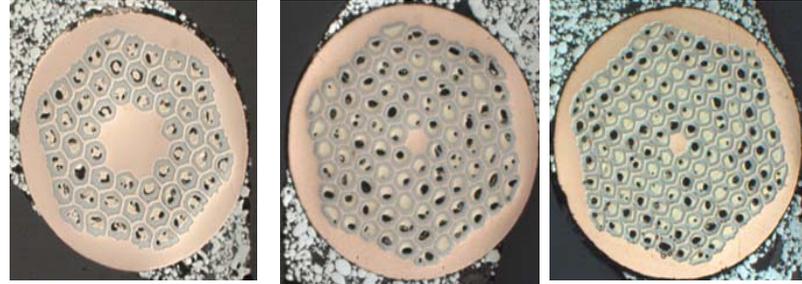
- Established “Workhorse”
 - 54/61 RRP
 - Will be tested in SR01 @ BNL

- Supporting measurements
 - Heat treat/RRR/ J_c
 - Stability

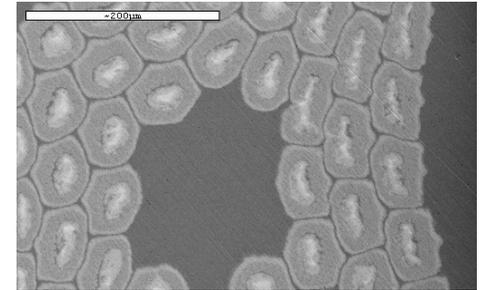
- Establishing measurement procedures

Cable

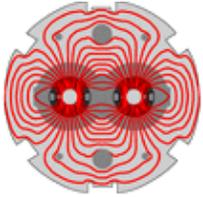
- Cables for several magnets produced



54/61



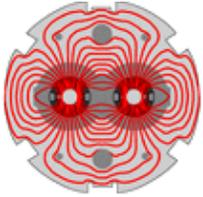
27-Strand
TQ



LARP

Materials

WBS				BNL	FNAL	LBL
2.4	Materials	Ghosh	1022	178	196	648
2.4.1	Conductor Support					
2.4.1.1	Strand R&D	Barzi	347	137	169	41
2.4.1.2	Cable R&D	Dietderich	301	41	27	233
2.4.1.3	Procurement	Ghosh	374			374



FY06 Accomplishments and Status

LARP

Model Magnet R&D

Quadrupole

TQ Mechanical Design Review
– February @ FNAL

—TQS01

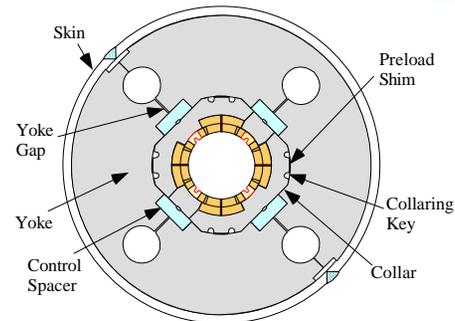
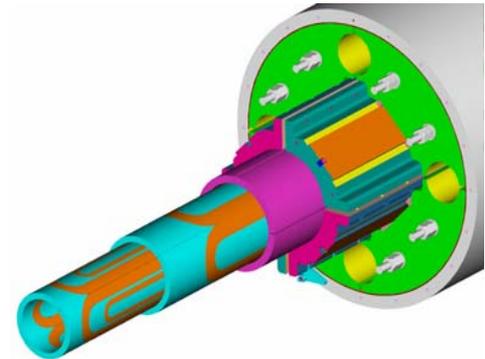
- Testing

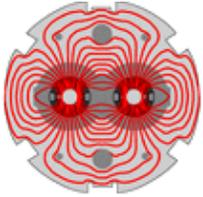
—TQC01

- In fabrication

—TQC02

- Cable evaluation

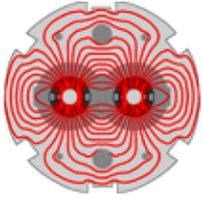




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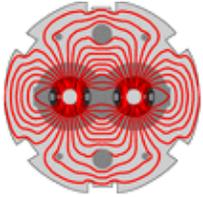
Model Magnet R&D

WBS				BNL	FNAL	LBL
2.2	Model Magnet R&D	Sabbi	2397	0	1334	1063
2.2.1	Technology Quadrupoles					
2.2.1.1	Technology Quad TQS01	Caspi	437		92	345
2.2.1.2	Technology Quad TQC01	Bossert	593		432	161
2.2.1.3	Technology Quad TQS02	Caspi	213		10	203
2.2.1.4	Technology Quad TQC02	Bossert	527		502	25
2.2.1.5	Coil/Structure exchange TQE01	Ferracin	87		37	50
2.2.1.6	Technology Quad TQS03	Caspi	278		108	170
2.2.1.7	Technology Quad TQC03	Bossert	262		153	109



LARP

TQS01

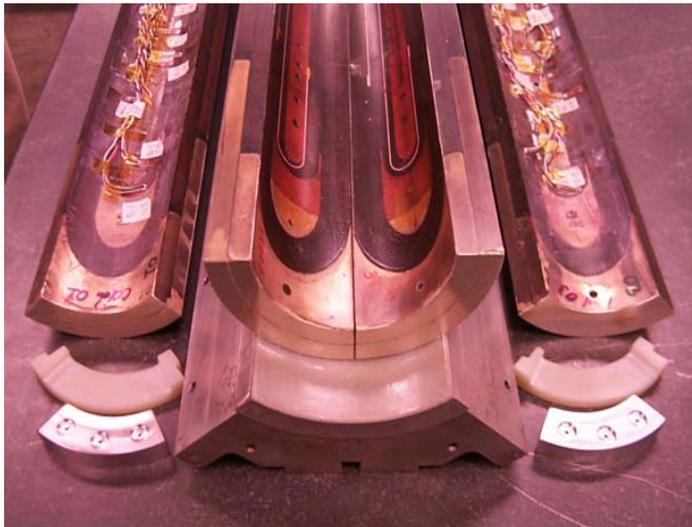


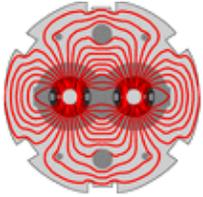
COIL-PACK SUB-ASSEMBLY

LARP

- **Coil Assembly**

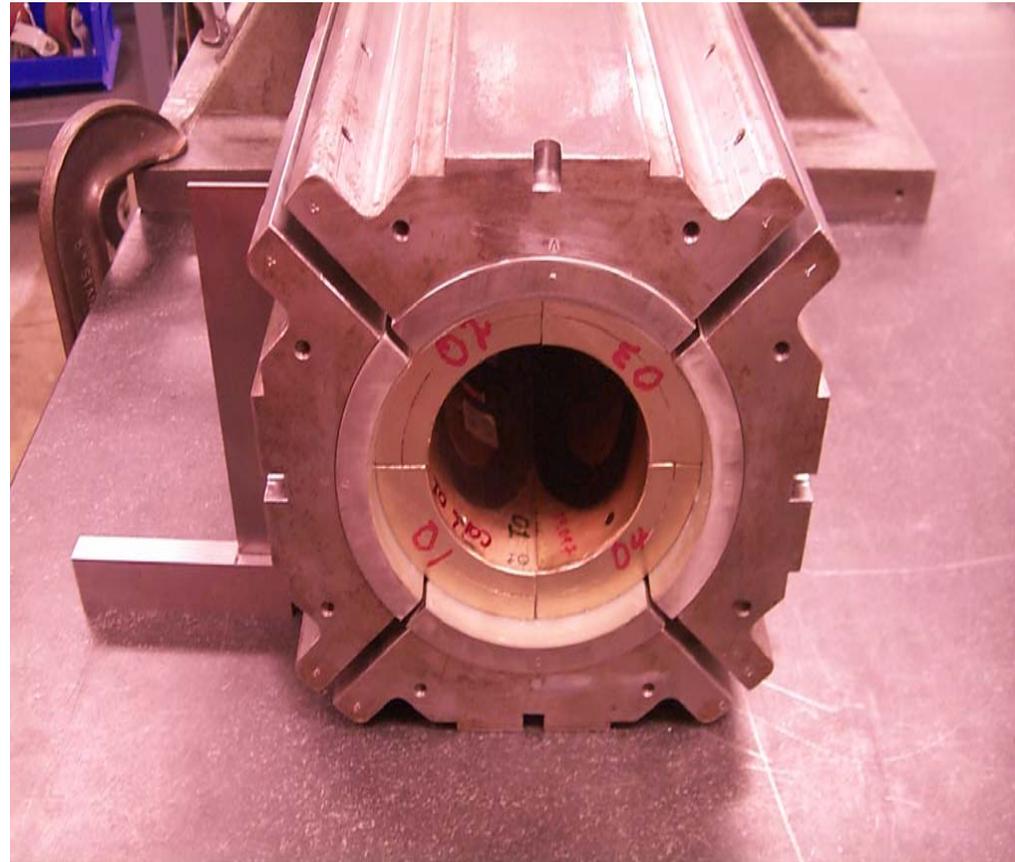
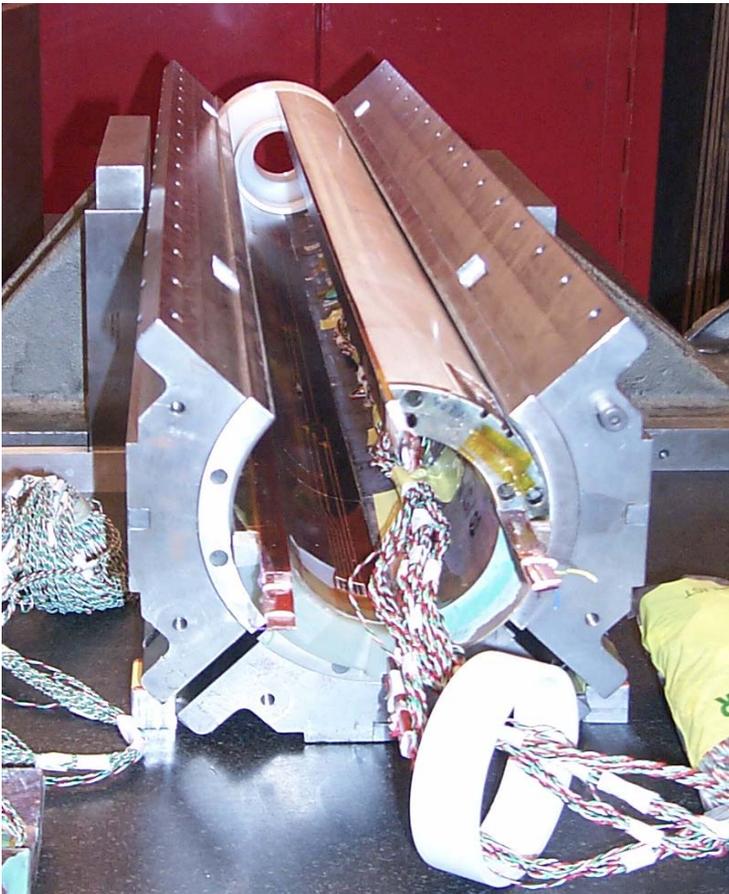
- .090" -thick NEMA G-10 ground-plane insulation between coils and load pads
- Ends are machined to provide precision surface for axial loading.

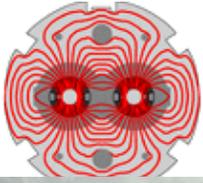




LARP

COIL-PACK SUB-ASSEMBLY, cont'd



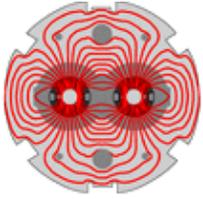


SHELL & YOKE SUB-ASSEMBLY, cont'd



- Load pads are assembled around a dummy coil .
- The dummy coil assembly is positioned within the yoke stacks
- The cylindrical shell is lowered around the yoke stacks.
- Bladders are inserted between load pads and yoke stacks – stretching the shell.
- Yoke gap keys are inserted in between the yokes, bladders deflated and removed– locking the shell against the yoke.

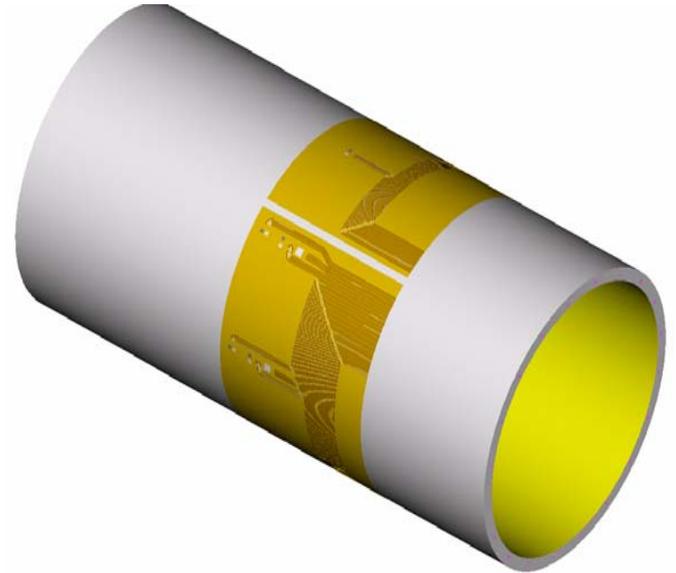
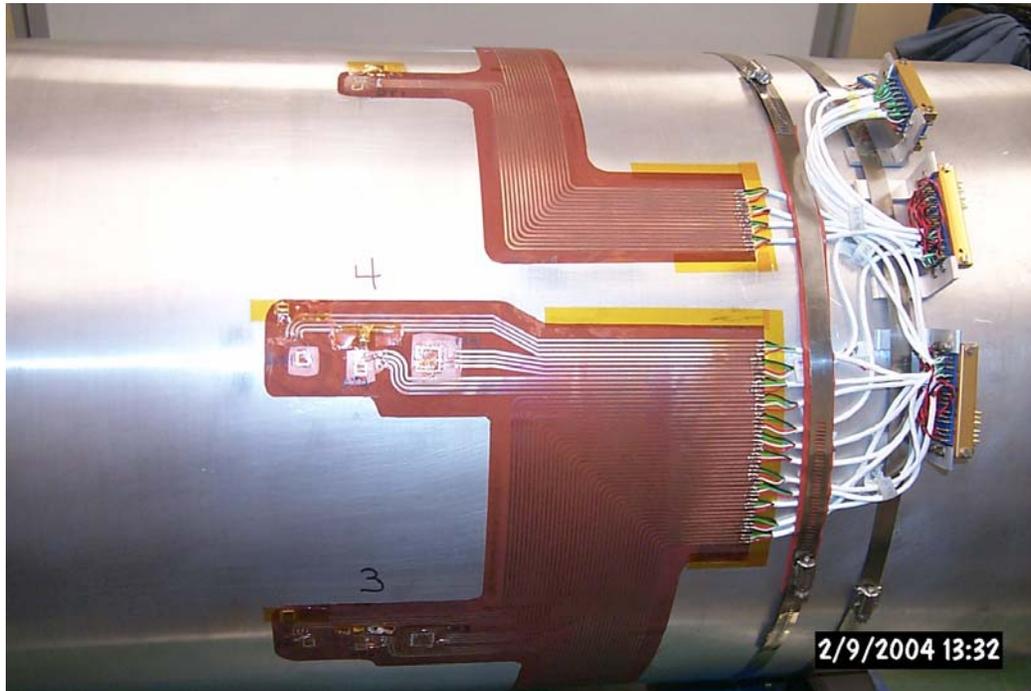


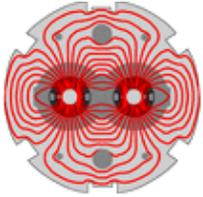


SHELL Strain Gauge Instrumentation

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- Shell strain gage instrumentation
—Multiple-gage traces



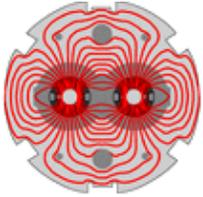


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Strain Gauge and Heater Trace

- Also applied to TQ layer 2 voltage tap and quench protection heater trace.
 - Trace medium used is stainless steel-on-kapton.

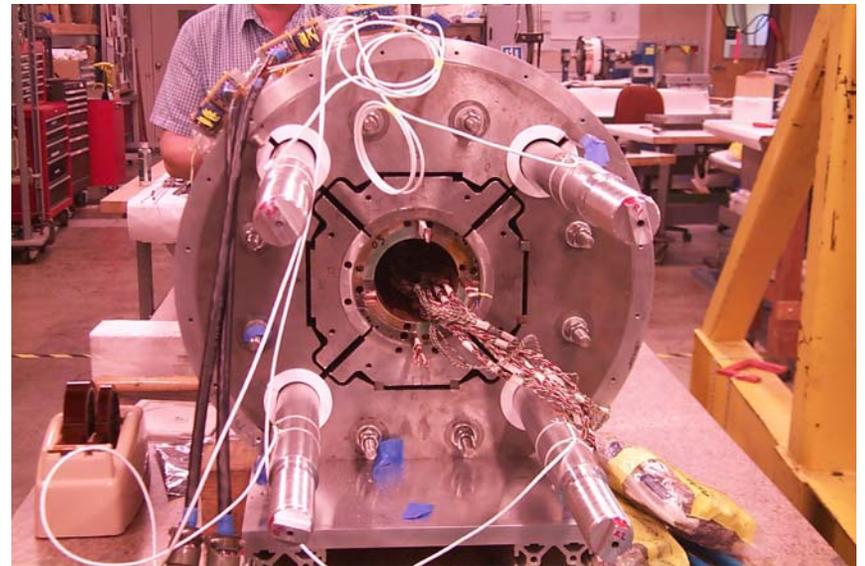


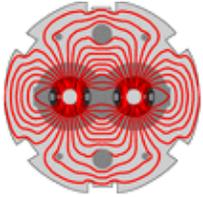


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FINAL ASSEMBLY

Mating the coil pack with the shell & yoke sub-assemblies.

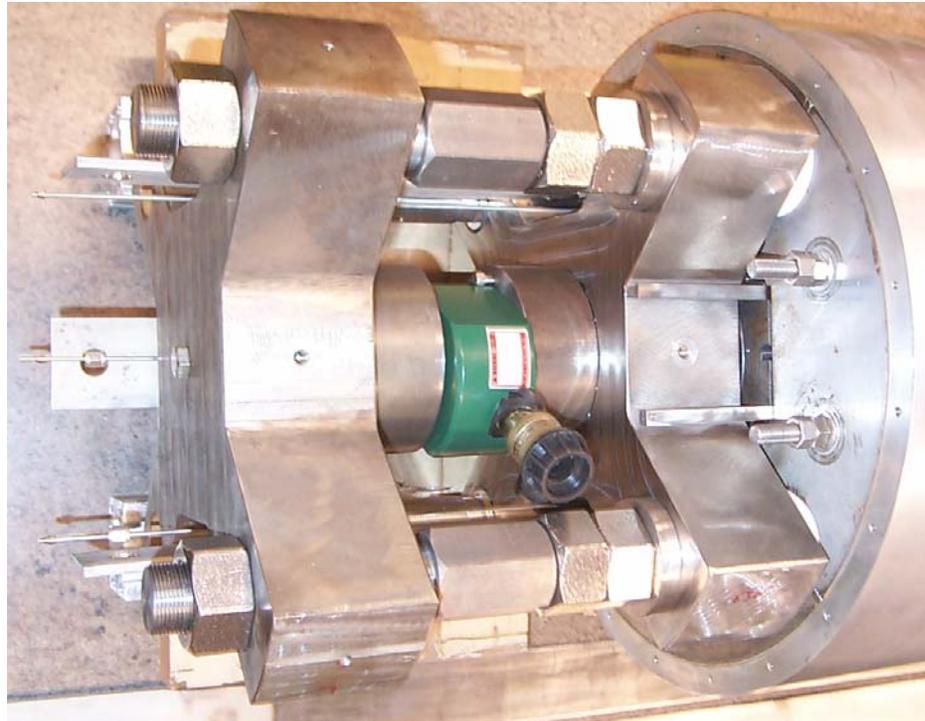


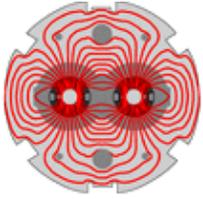


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AXIAL LOADING

- **25 -Ton hydraulic actuator (9500 psi)**
- **Axial Loading Rig – rod tensioning operations**
 - **Dial indicators measure rod stretch during room temperature loading operations.**



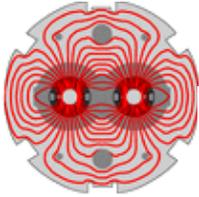


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AZIMUTHAL LOADING

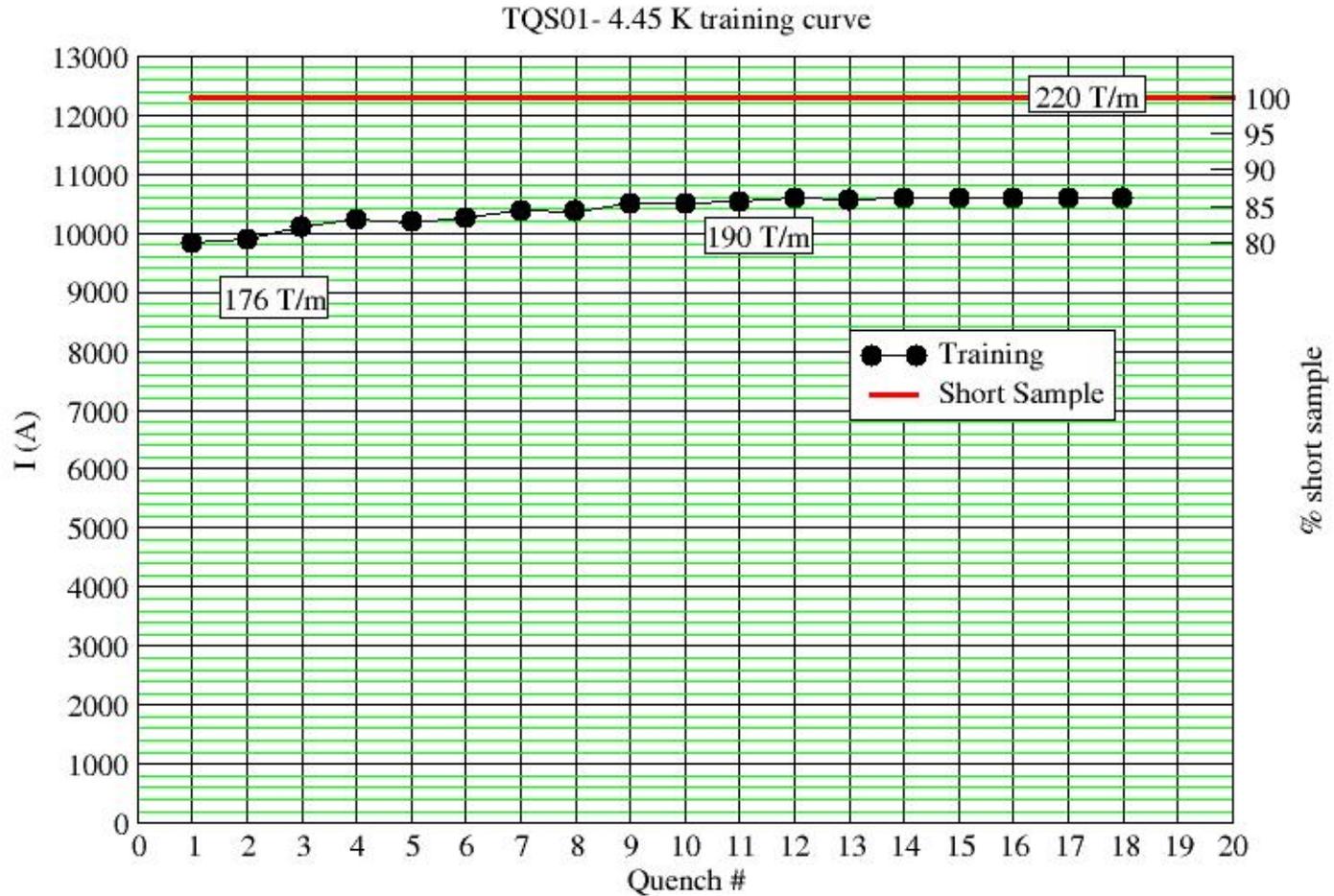
- Bladder operations – up to 10,000 psi (water pressure).
- All axial rod and shell strain gages are continuously monitored and recorded throughout entire operation.



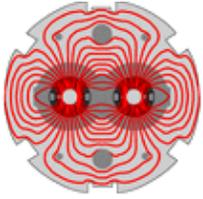


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TQS01 Quench History

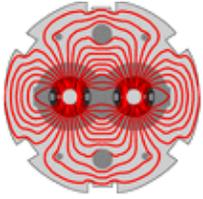


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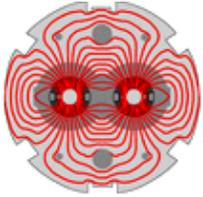
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TQC01



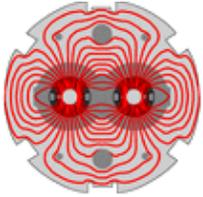
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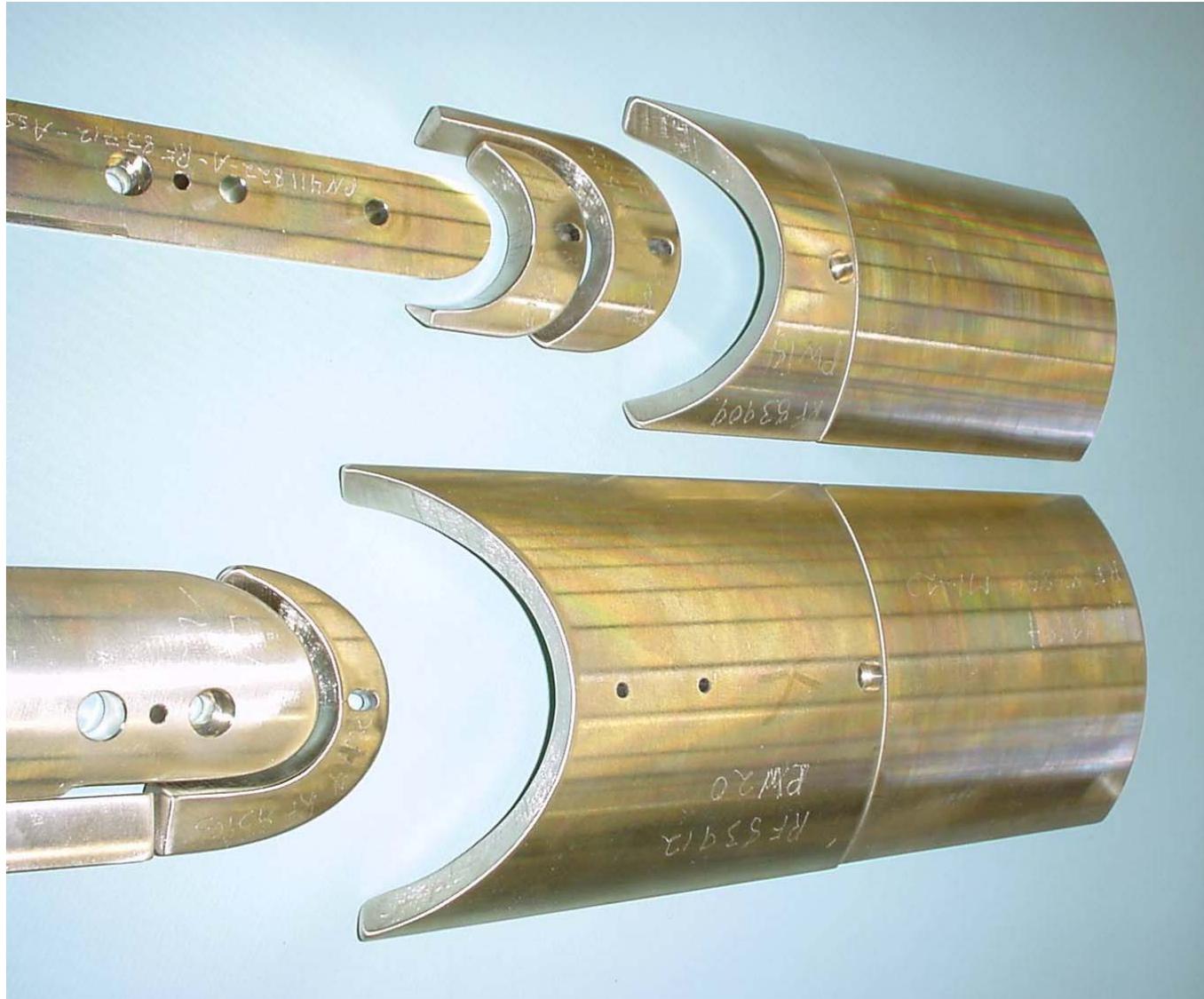


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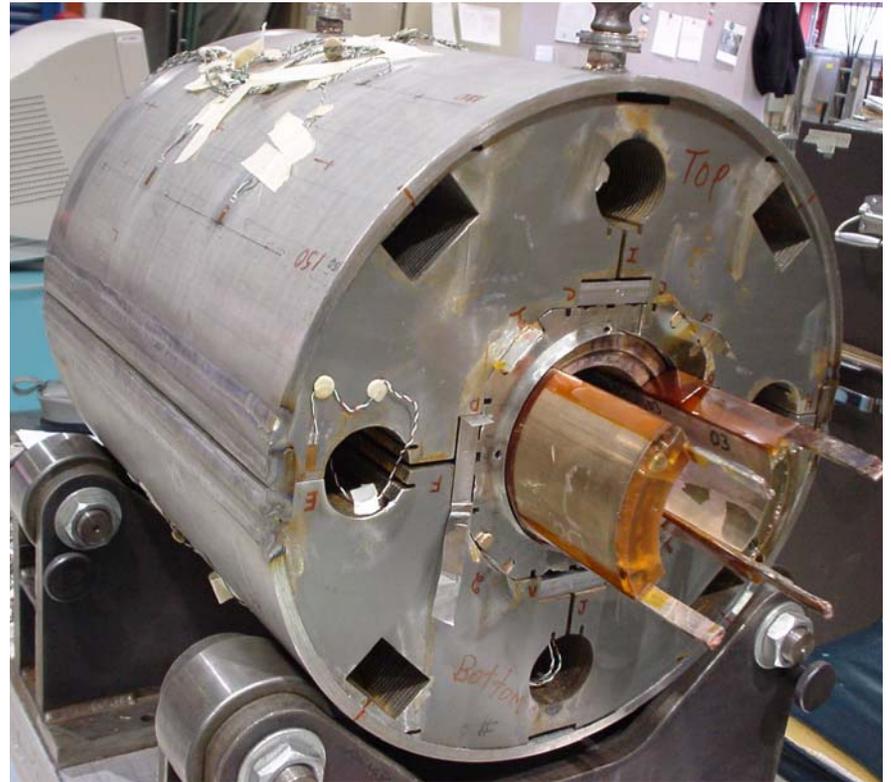


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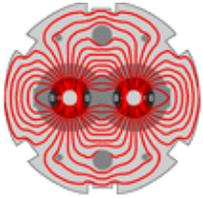




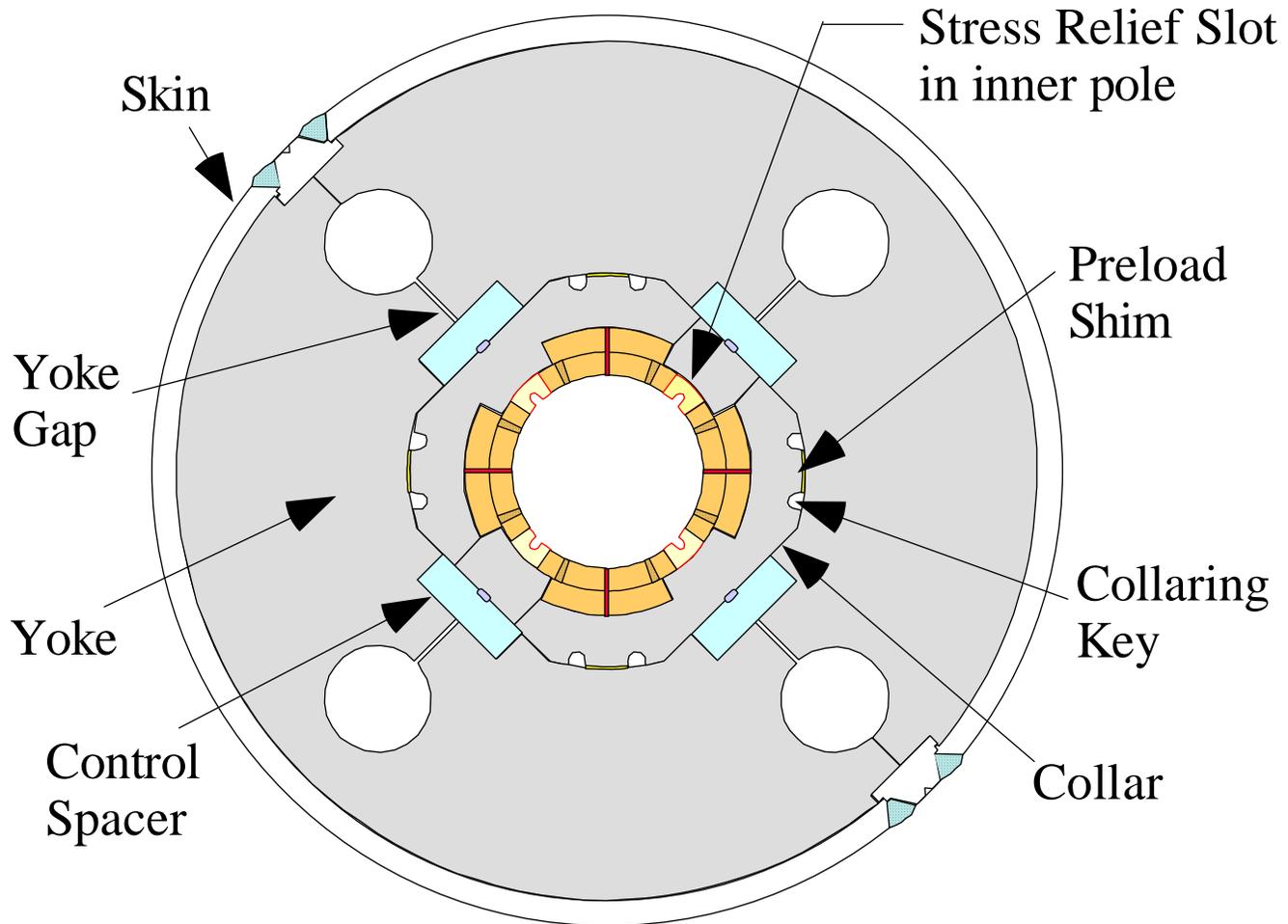
Preliminary Model



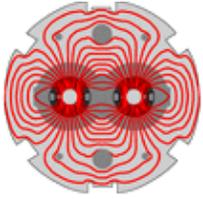
TQC Mechanical Model with coils



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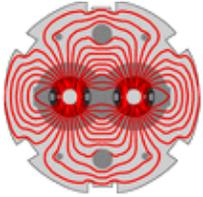
TQC cross-section.



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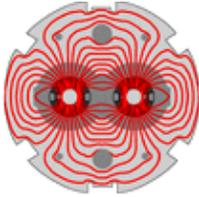
Mechanical Model Construction



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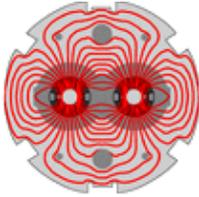
Mechanical Model Construction



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Current Status

- **Model Magnet R&D**
 - TQS01 (Test in progress)
 - TQC01 (June)
 - TQC02 Fab and test by end of FY06
 - TQE01 assembly and test by end of FY06
- **Supporting R&D**
 - SQ-01 completed in FY04 and retested in FY05
 - SQ-02 recently retested at FNAL @ 1.8K
 - Long Racetrack (LR) underway
- **Materials**
 - Characterization of strand and procurement
- **Design Studies**
 - Relevant studies underway



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Some goals for this meeting

- **Continue program integration efforts**
 - **Lots of progress so far**
- **Assess progress in FY06**
- **Develop FY07 program**
- **Extend outlook to beyond FY09**
- **Assess new task proposals in context of program priorities**
- **Main elements remain . . .**
 - **TQ program – technology development, reproducibility, integration**
 - **LR program – long coil scale-up**
 - **LQ program – eye on the prize**
 - **Continued progress on conductor issues**