Lawrence Berkeley National Laboratory

U.S. LARP

Coil Task Force Summary

Helene Felice

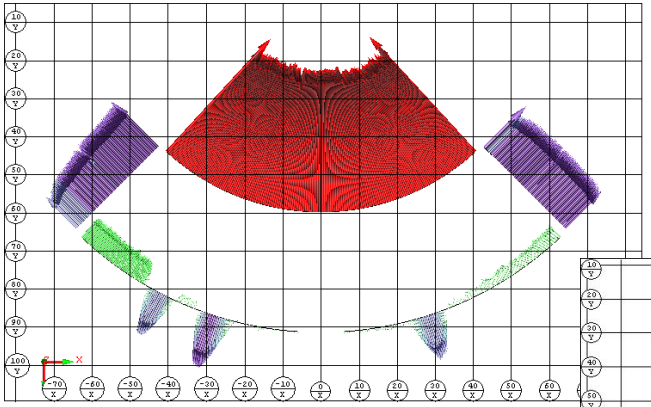
Collaboration Meeting, Montauk NY – May 16th to 18th 2011

G. Ambrosio – D. Bocian – H. Felice – J. Krishnan – D. Dietderich

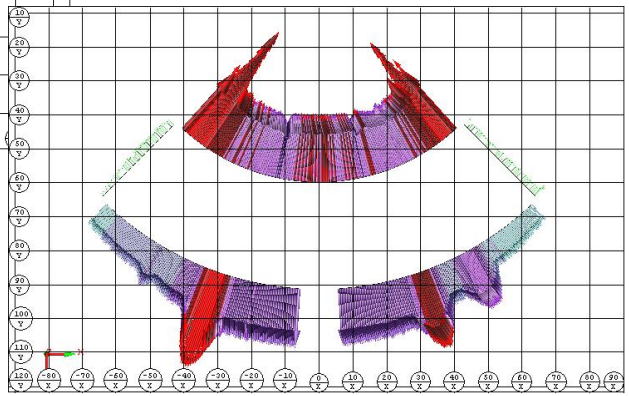
Observation on standard HQ coils Radial Dimensions

HQ CMM measurements

1 square = 100 microns (4 mils)



HQ03 – FNAL – post-test
- normalized to outer radius
- 619 mm from lead end
- normalized to all surfaces



HQ04 – FNAL – post-test
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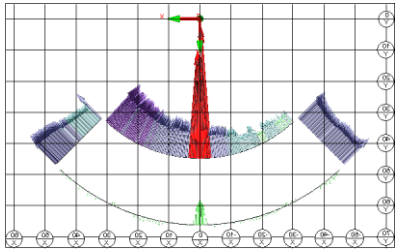
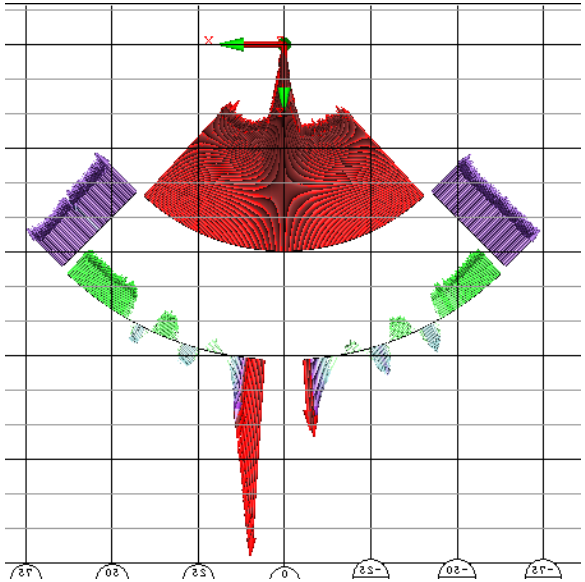
LQ05





From CMM measurements
- both coils are oversized radially of 12 to 15 mils (300 to 375 microns) => different wrt LQ/TQ
- both coils are oversized azimuthally of ~ 5 mils (125 microns) => similar to LQ

Radial coil size: from VMS measurements

Radial measurement with VMS:

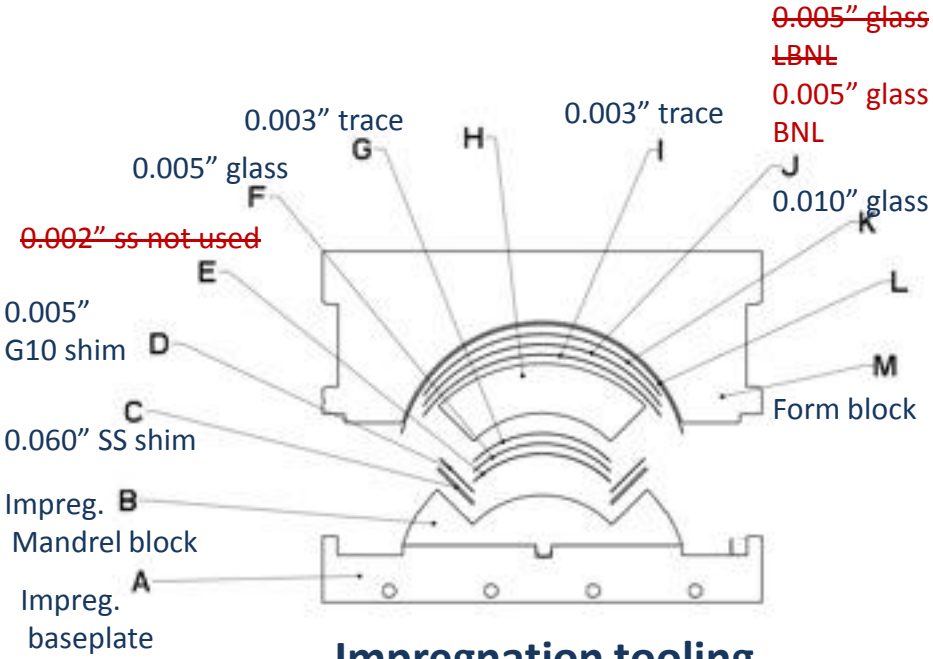
Radial width of the HQ03 NT (avg): 32.074 mm
Radial width of the HQ06 (avg): 31.970 mm

Nominal radial size of the cavity: 31.725 mm

⇒ **HQ03 NT: 349 microns oversized**
⇒ HQ06: 245 microns oversized

Consistent with CMM measurements for HQ03

HQ coils radially oversized

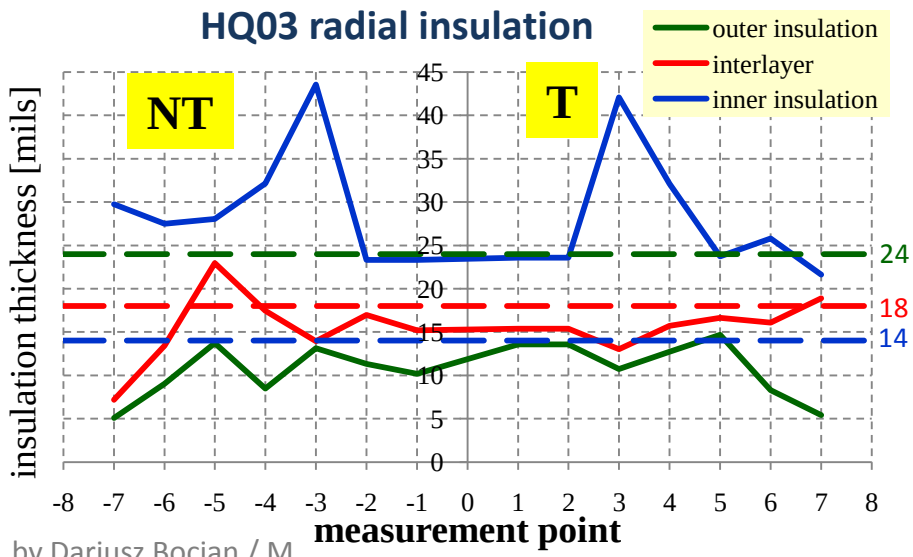


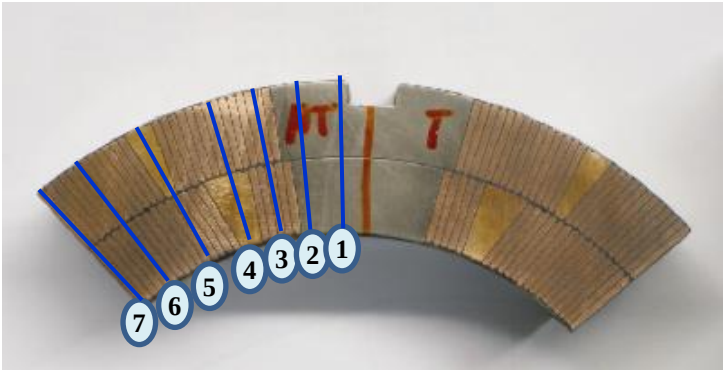
Impregnation tooling

Distribution of radial insulation in the cavity – Nominal Conditions

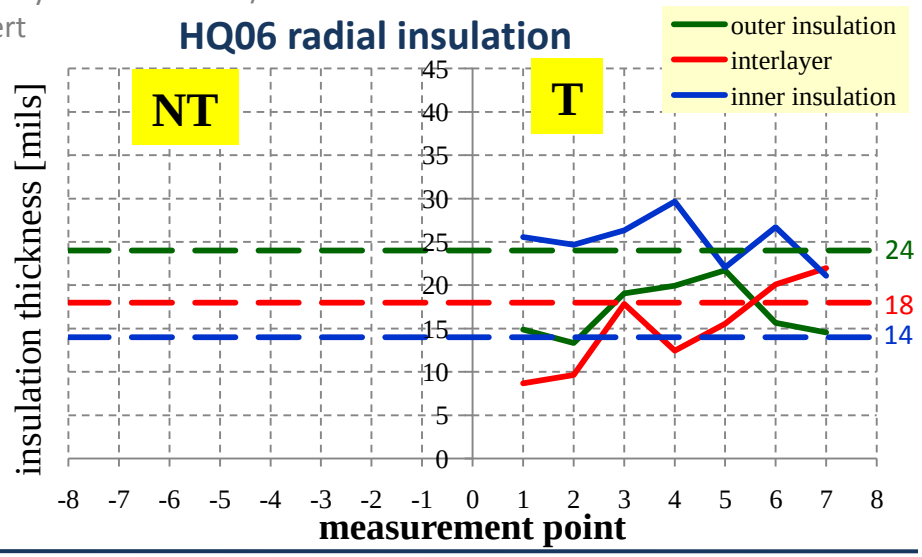
Nominal radial insulation + void

- **ID** **14 mils** (2+5+3+4)
- **Interlayer** **18 mils** (4+10+4)
- **OD** **24 mils** (4+3+10+5/5+2)





Meas. by Dariusz Bocian / M. Bossert



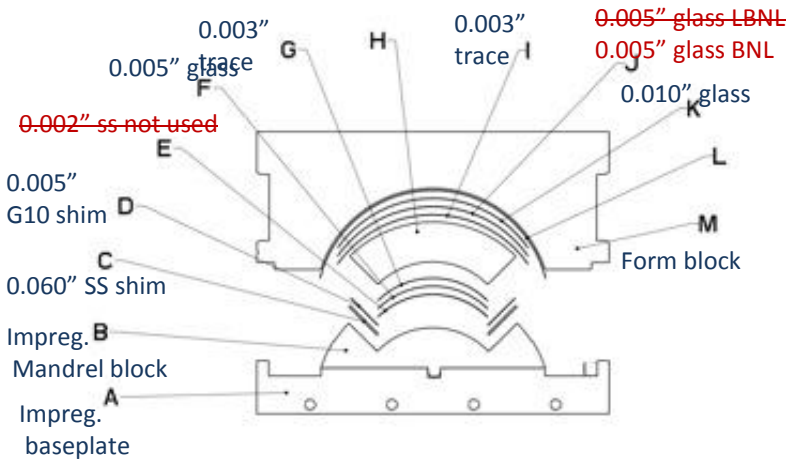
Re-distribution of radial insulation in the cavity

Nominal radial insulation + "void"

- **ID** **14 mils** (2+5+3+4)
- **Interlayer** **18 mils** (4+10+4)
- **OD** **24 mils** (4+3+10+5/5+2)

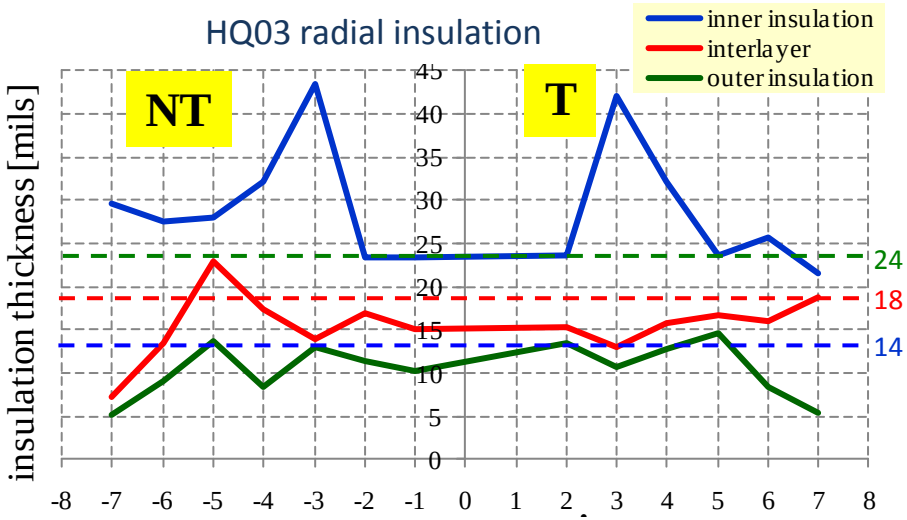
If coil moved outward in the cavity => "void" moved inward modifying the insulation+ void distribution

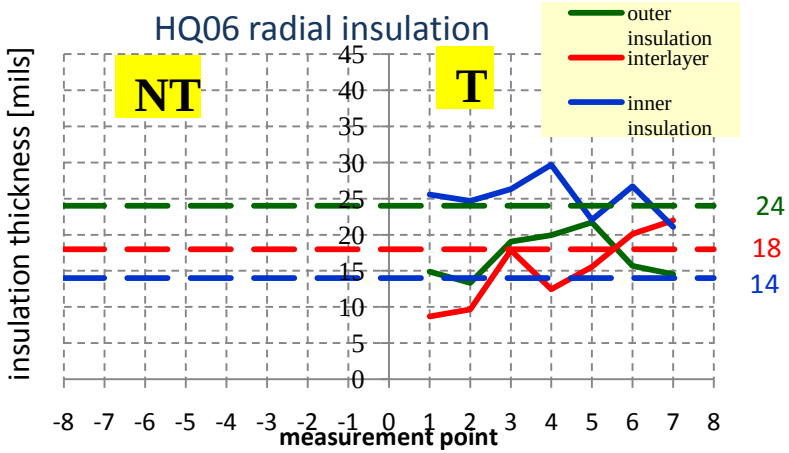
- **ID – HQ03** **21 mils** (2+5+3+4 + 5 +2)
  HQ06 **16 mils** (2+5+3+4 +2)
- **Interlayer** **18 mils** (4+10+4)
- **OD** **17 mils** (4+3+10+5)



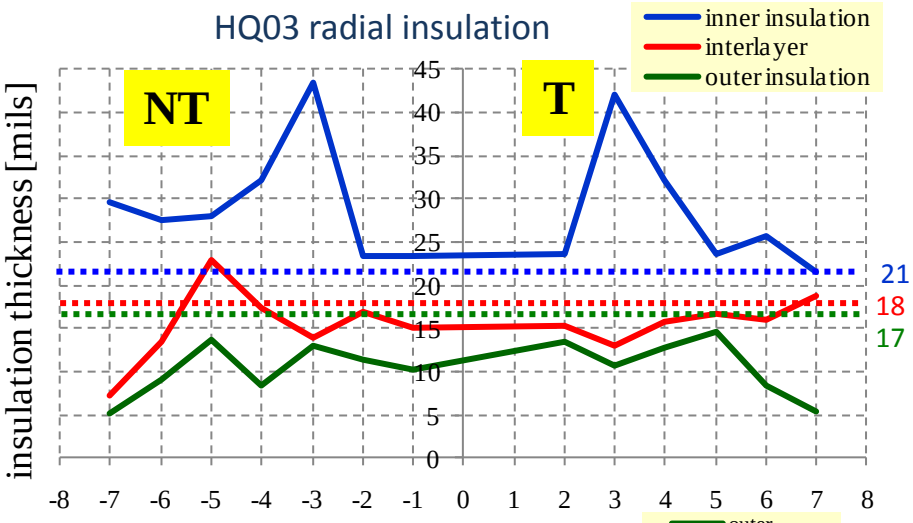
Comparison of the radial insulation distribution

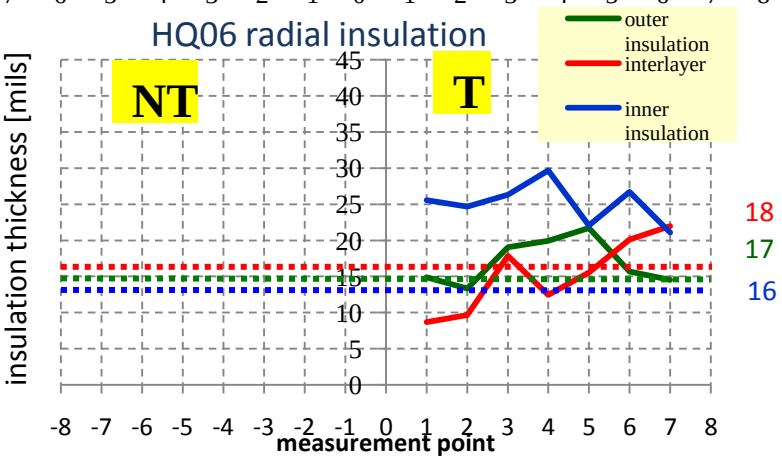
Comparison with nominal conditions





Comparison with redistributed void in the cavity

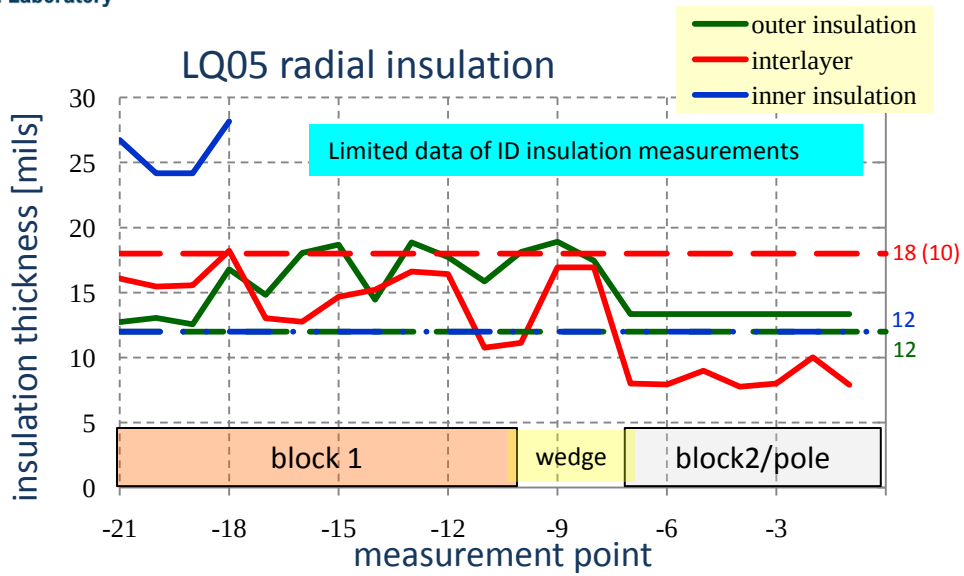


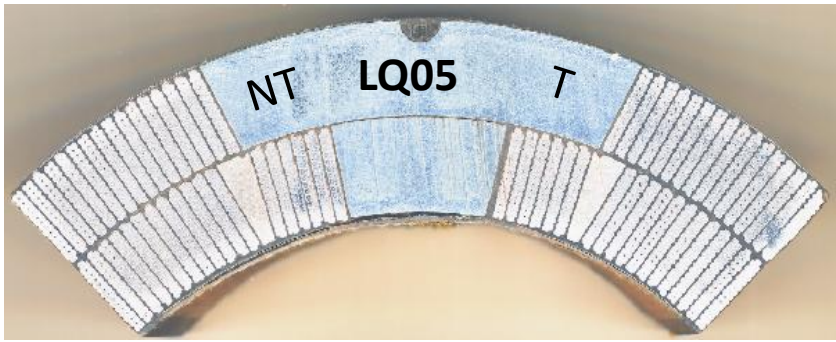


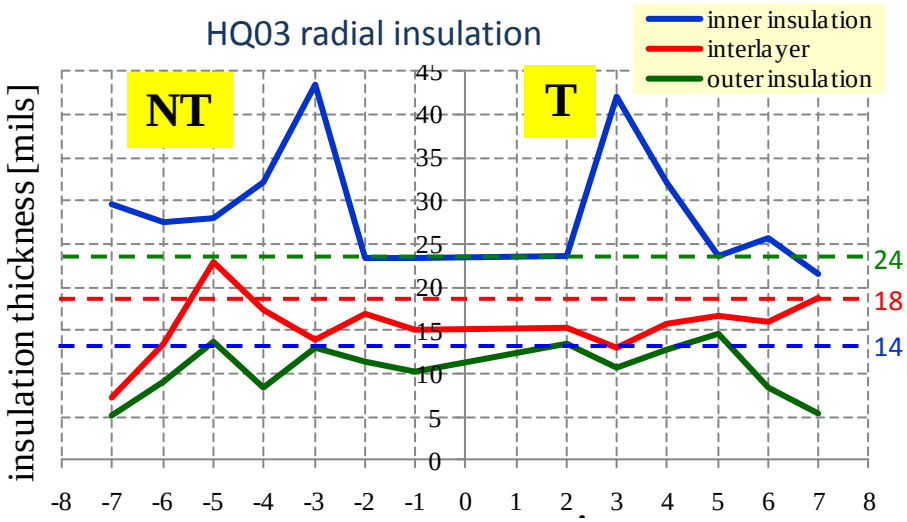
- Radial displacement of the coil outward

Meas. by Dariusz Bocian / M. Bossert

Comparison with LQ05







- No strong compaction of the OD insulation in LQ
- Large insulation on ID in both cases

Cable width growth

		HQ03	HQ06	LQ05	TQ19
Cable		991R	1000R	953R	946R
Cable MM width	mm	15.113	15.073	10.062	10.0615
Cable nominal width		15.15	15.15	10.05	10.05
Cable MM thickness	mm	1.444	1.44	1.261	1.2655
Cable nominal thickness	mm	1.44	1.44		
Cross section measurements					
Average width	mm	15.31	15.19	10.26	10.158
Average increase w	microns	197.0	117.0	198.0	96.5
Average increase w	%	1.3	0.8	2.0	1.0
Average thickness	mm	1.47	1.46	1.332	1.342
Average increase t	%	1.8	1.4	5.6	6.0

Computed with respect to nominal/design value (15.15 mm in case of HQ)

Total cable growth wrt nominal	microns	320	80
Nominal Void in the cavity	microns	228.6	101.6
	mils	9	4
Add. space occupied by the cables	microns	91.4	-21.6
	mils	4	-1

The cable will first fill the void – remaining space needed to account for total cable growth – valid on mid-plane

Meas. by Dariusz Bocian / M. Bossert

- Consistency between HQ and LQ/TQ
- Increase of cable width during reaction does not seem to drive the radial oversized dimension
- Nevertheless, cable redesign should account for cable growth and new insulation

Considerations about cable width for HQ/LHQ

- **Insulation contribution** (Rodger's slides 03/03/2011 HQ Meeting):
  - Eglass double butt wrap => 195 microns per turn (both sides) at 10 MPa
  - Sleeve => 180 microns

- **cable growth : within 1 to 2 %**

=> Requires additional radial space (wrt nominal) of 150 to 300 microns

For the same cavity HQ - including the 20 mils interlayer and void

E-glass doublebutt at 10 Mpa IL	**microns**	**+195**
E-glass doublebutt at 10 Mpa OL	**microns**	**+195**
Add interlayer wrt design - 10 mils	**microns**	**+250**
Design insulation in the cavity - 2 layers	**microns**	**-400**
Void = space available 9 mils	**microns**	**-230**
2% cable growth	microns	+303
1% cable growth	microns	+151.5
Total add space 2% both layers	microns	616
Total add space 1% both layers	microns	313
New cable width for 2%	mm	14.842
New cable width for 1%	mm	14.9935

- additional conditions can be considered:
  - sleeve: range of 14.9 to 15 mm
- different void in the cavity 4 mils instead of 9 mils
  - Eglass: 14.8 to 14.9 mm
  - Sleeve: 14.8 to 14.9 mm

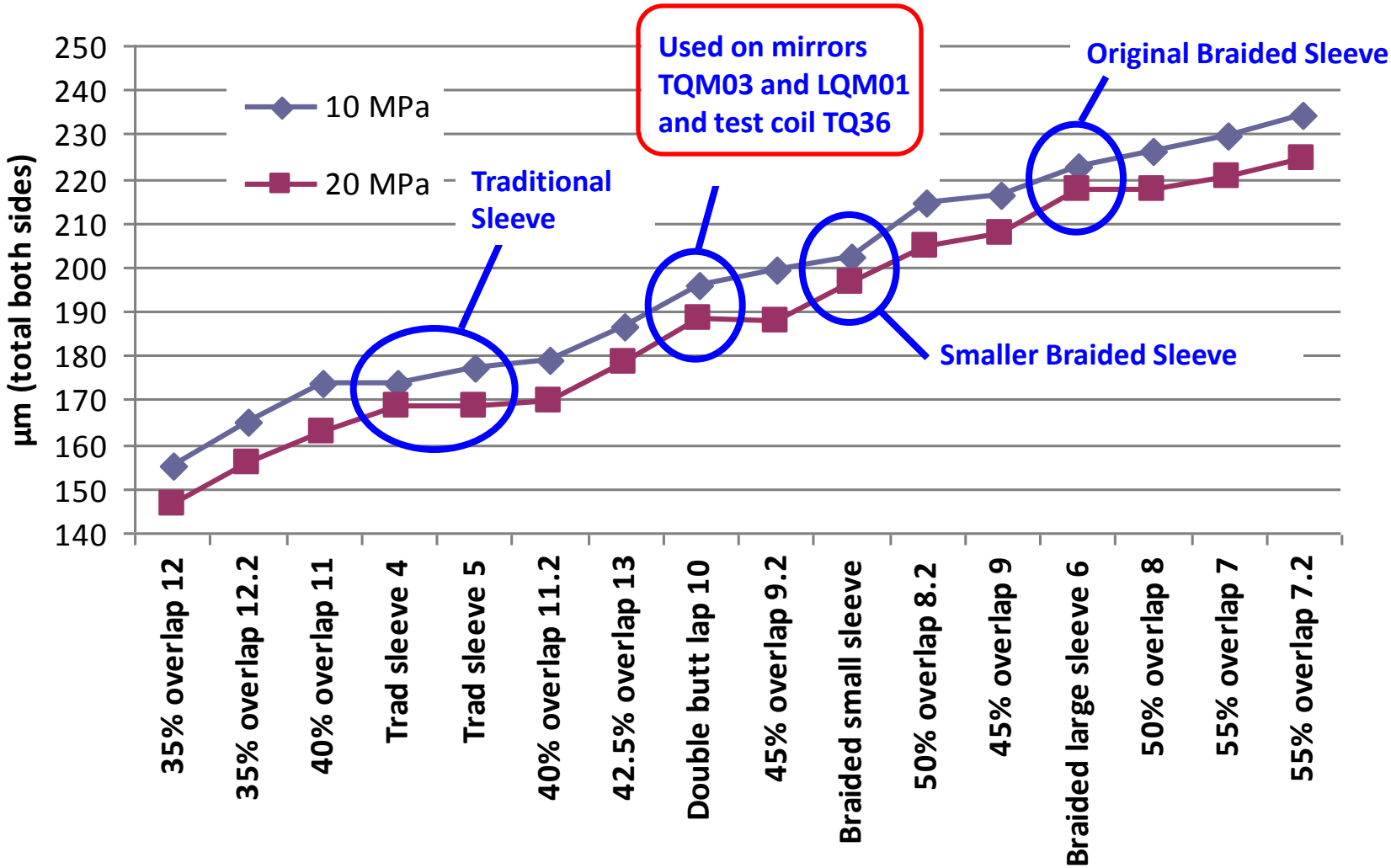
Cable R&D: Options from Dan's talk on HQ Meeting 03/31/2011

⇒ **1015-I**: 0.778 mm 35 st **14.778 mm** – 1.349 mm – 0.723 KS

⇒ **1014-P2**: 0.8 mm 34 st **14.785 mm –** 1.345 mm – 0.718 KS

⇒ **1014-P1**: 0.8 mm 34 st **14.776 mm –** 1.385 mm – 0.722 KS

Insulation Thickness of Cured 10 stacks measured at 10 and 20 MPa

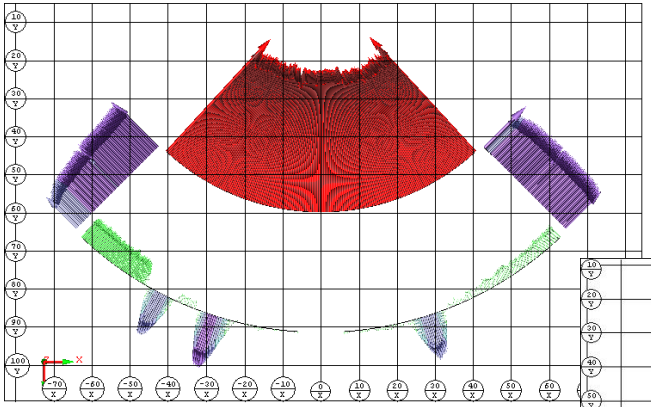


Meas. by R.Bossert

Observation on standard HQ coils Azimuthal Dimensions

HQ CMM measurements

1 square = 100 microns (4 mils)



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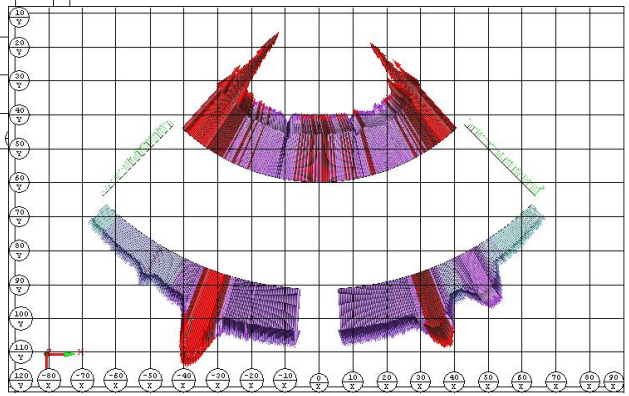
- normalized to all surfaces



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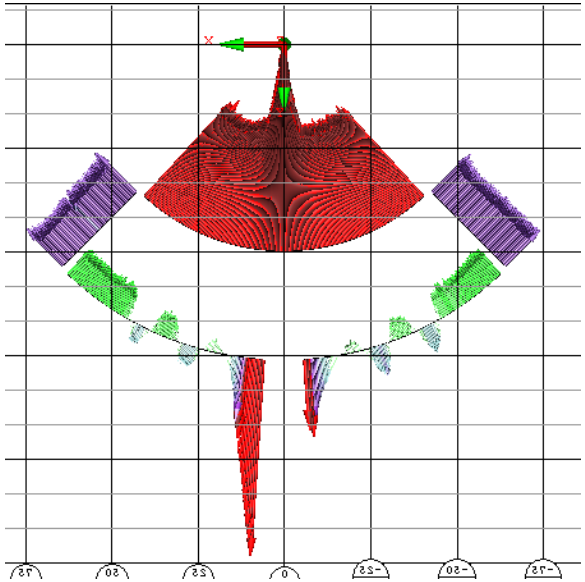
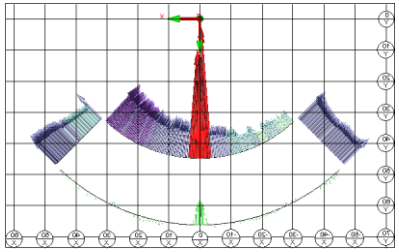


LQ05



From CMM measurements

- both coils are oversized radially of 12 to 15 mils (300 to 375 microns) => different wrt LQ/TQ
- both coils are oversized azimuthally of ~ 5 mils (125 microns) => similar to LQ

Cable mid-thickness growth

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Meas. by Dariusz Bocian / M. Bossert

		HQ03	HQ06	LQ05	TQ19
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Different annealing time between HQ03 (4 hours at 200 deg) and HQ06 (16 hours at 200 deg) => Real difference or noise of the measurement

Total cable azim growth wrt nominal	microns	30	20	72	82
Additionnal insulation not accounted for (pole)	mils	7	0	0	0
	microns	178	0	0	0
Distributed over layer 1 (42 sides)	microns	4	0	0	0
Distributed over layer 2 (54 sides)	microns	3	0	0	0
Design insulation per side	microns	100	100	125	125
Computed insulation layer 1 per cable side	microns	81	90	89	84
Computed insulation layer 2 per cable side	microns	82	90	89	84
Average insulation measured	microns	**87**	**94**	**96**	**93**
Compaction of the insulation (wrt 100 microns)	%	**14**	**7**	**5**	**8**

Compaction of the cable due to cable growth and add. material

- Cable azimuthal growth reduced in HQ (1.5 to 2%) wrt to TQ/LQ (6%)
- Measured HQ coils are with 108/127 whereas TQ/LQ are with 54/61
- Equivalent insulation compaction in HQ and TQ

Implication for cable thickness in HQ/LHQ

- **Insulation contribution** (Rodger's slides 03/03/2011 HQ Meeting):
  - Eglass double butt wrap => 195 microns per turn (both sides)
  - Sleeve => 180 microns

- **cable growth : 6 %**

=> Requires additional azimuthal space (wrt nominal)

For the same cavity HQ

E-glass doublebutt (2)	**microns**	**195**
Design insulation per turn	**microns**	**200**
6% cable thickness growth	microns	86.4
Total room required for cable growth	microns	81.4
New cable thickness	microns	1.36

- **Cable R&D**: 1015 with 35 strands (Dan's talk on HQ Meeting 03/31/2011)

⇒ **1015-I**: 0.778 mm 35 st 14.778 mm – **1.349 mm** – 0.723 KS Jc?

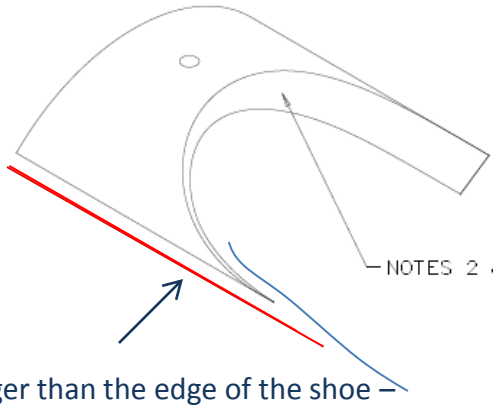
⇒ **1014-P2**: 0.8 mm 34 st 14.785 mm – **1.345 mm** – 0.718 KS more deformation / Jc?

Status on HQ “special” coils

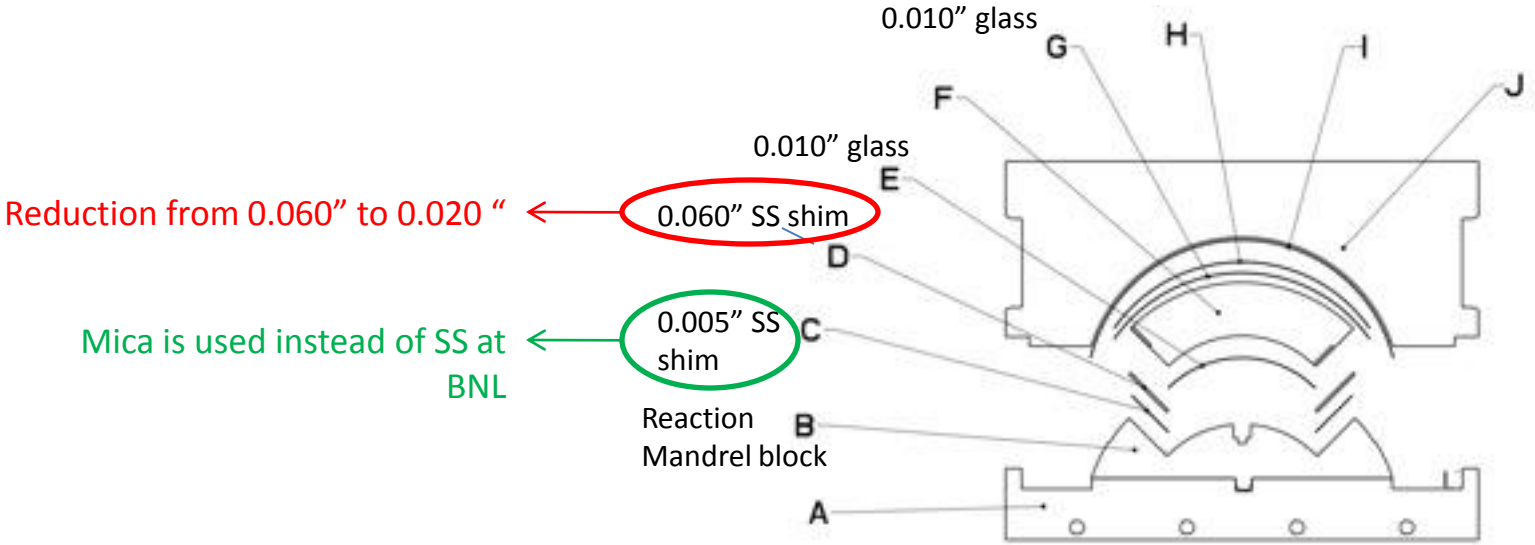
Case of HQ12

Increase of the azimuthal space in the cavity:

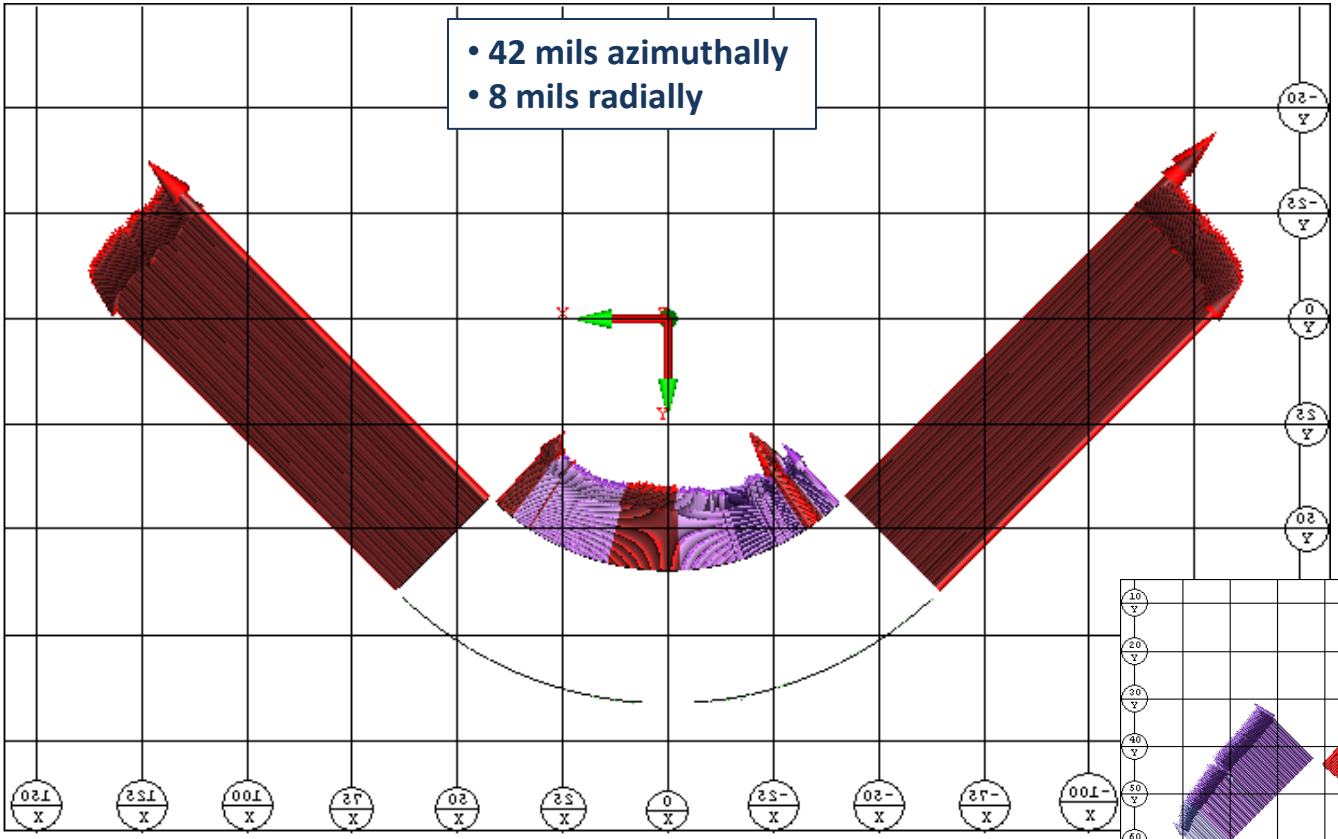
- azimuthal shim decreased from 60 to 20 mils
  - Total of 40 mils per side (~ 1 mm)
  - provides 50 microns per turn in the IL (3.5 %)
  - provides 39 microns per turn in the OL (2.5%)



Feathered shim longer than the edge of the shoe – work in progress

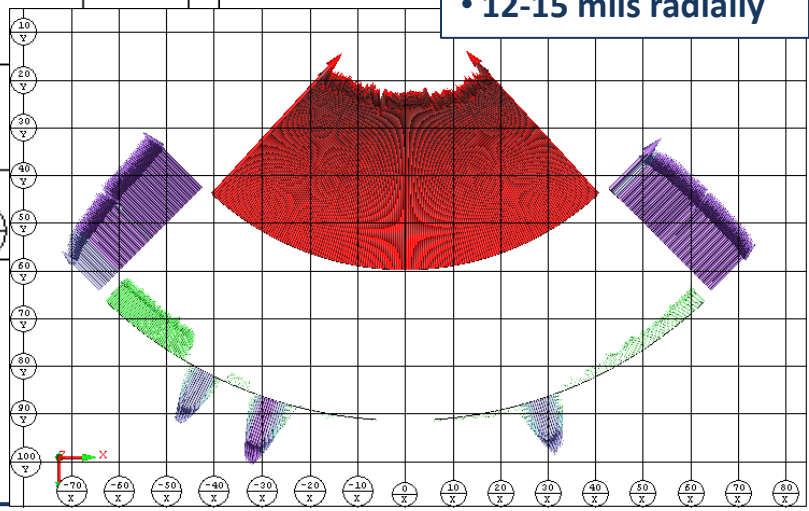


HQ12 CMM measurements



HQ12 – FNAL – before mirror test
- 630 mm from lead end
- 1 square = 250 microns = 10 mils

HQ03 – FNAL – post-test
- normalized to outer radius
- 619 mm from lead end
- 1 square = 100 microns = 4 mi



- Increasing the azimuthal space per turn seem to improve the radial situation
- Improvement of performance? => Mirror test

HQ13

Increase of the azimuthal space in the cavity:

- 1 turn removed in both layers
  - 1.44+2*0.086=1.612 mm (using insulation a 1000 psi)
  - provides 80 microns per turn in the IL (5.5 %)
  - provides 62 microns per turn in the OL (4.3%)

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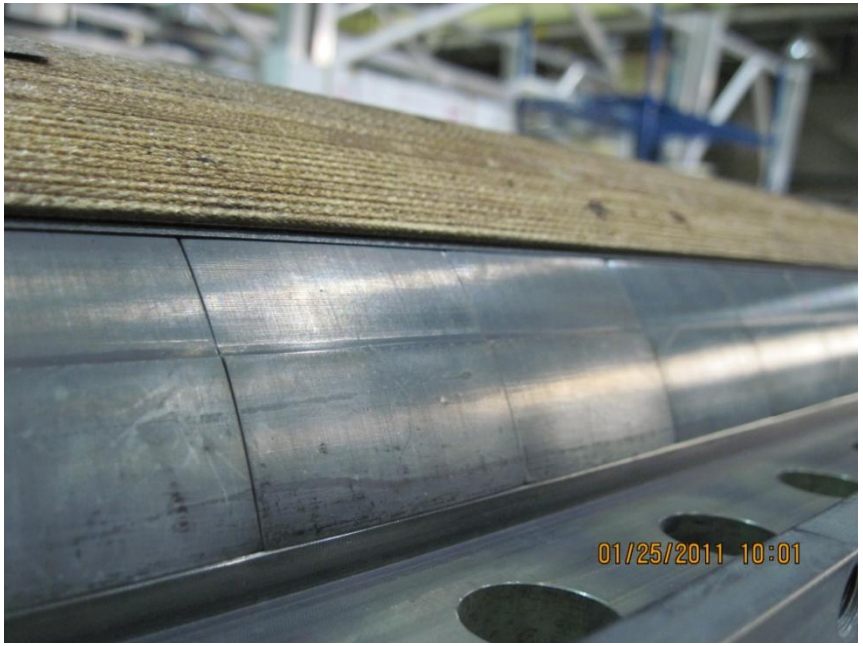
LQ / HQ comparison

LQ 16

Jesse Schmalzle

HQ13



Jesse Schmalzle

Error analysis

	Av_Tpre	Av_Tpost	STDEV (Tpost)	STDEV (av_Tpost)	CTI	Error
	um	um	um	um		
HQ03 NT	1444	1474	22	3.3	**2.0%**	**0.2%**
HQ03 T	1444	1470	24	3.5	**1.8%**	**0.2%**
HQ06 Sing Pass	1440	1460	30	4.4	**1.4%**	**0.3%**
TQ19 NT	1266	1342	22	3.7	**6.0%**	**0.3%**
TQ19 T	1266	1335	18	3.1	**5.5%**	**0.2%**
LQ05 NT*	1261	1331	15	2.5	**5.6%**	**0.2%**

LQ sample was measured with VMS; all other samples were measured with Microscope, therefore there is an additional error when comparing LQ sample to the others

➔ Error of comparison ~ 0.3% (to be confirmed)

Summary and open questions

- The HQ coils 6 and 3 are oversized radially of 245/350 microns – also observed on CMM measurements
- Not clear if it is on the OD or the ID of the coil

- insulation distribution radially modified with respect to nominal => coil moving outward

- The cable radial growth is consistent between HQ an LQ/TQ measurements 1 to 2 %
- The cable azimuthal growth is smaller in HQ than in TQ/LQ: 2 instead of 6%
- 108/127 strands in HQ - 54/61 strands in TQ/LQ

- Why is the coil oversized radially instead of azimuthally since the main cable growth is azimuthal

- is HQ performance only related to the coil compaction during fabrication? => Coil 12/13 mirror tests

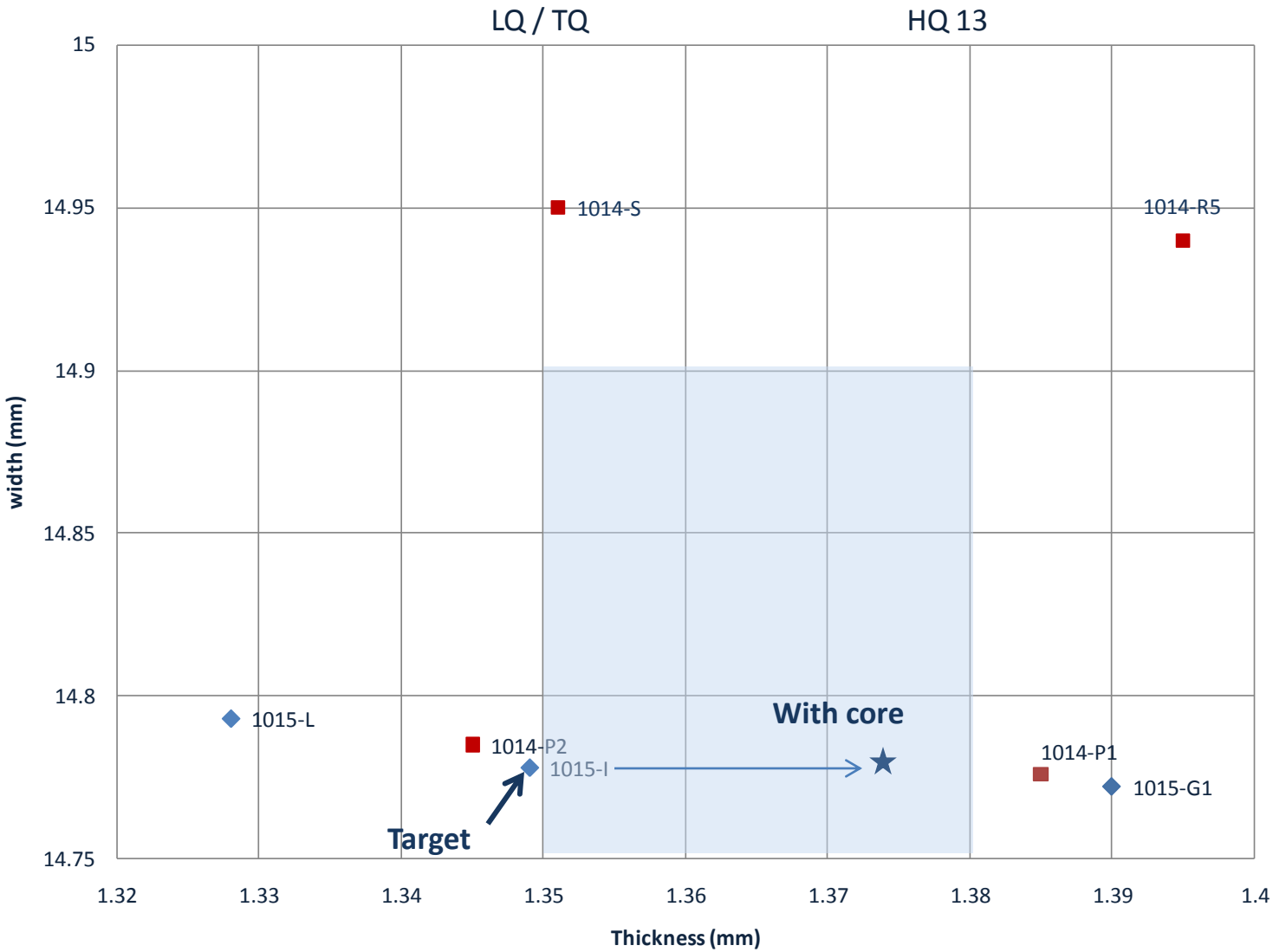
HQ14 proposal

Observations

		Cable	Annealing	Thickness		Width	
				%	microns	%	microns
Measured	LQ 05	953R		5.6	71	2	198
	TQ 19	946R		6	76	1	96.5
	Unconfined HQ cable	1008	>180 for 2 hours	4	58	1.7	257
		1000R	200 for 16 hours	1.5	22	1.8	271

Computed	HQ 12	1012 SS core	>175 for 2 hours	still coming out of the tooling			
				2.5 - 3.5	40-50		
	HQ 13	1008	>180 for 2 hours	still coming out of the tooling			
				4.3 - 5.5	62 - 80		
	HQ?			5.6-6	80-86	1-2	150-300

Target: 1.35 to 1.38 mm thick cable

14.85 to 15 mm wide cable
Target accounting for additional interlayer insulation and void in the cavity: 14.8 to 14.9 mm

Available cables: target definition