EIC
High Gradient Actively Shielded Nb3Sn Quadrupole

Michael Anerella

Brookhaven National Laboratory

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Collaboration

- BNL (M. Anerella) – design, fabrication, test
- LBNL (G. Sabbi) – 3-D analysis, consultation on assembly loading
- Jlab (T. Michalski) – parts fabrication & procurement, testing participation

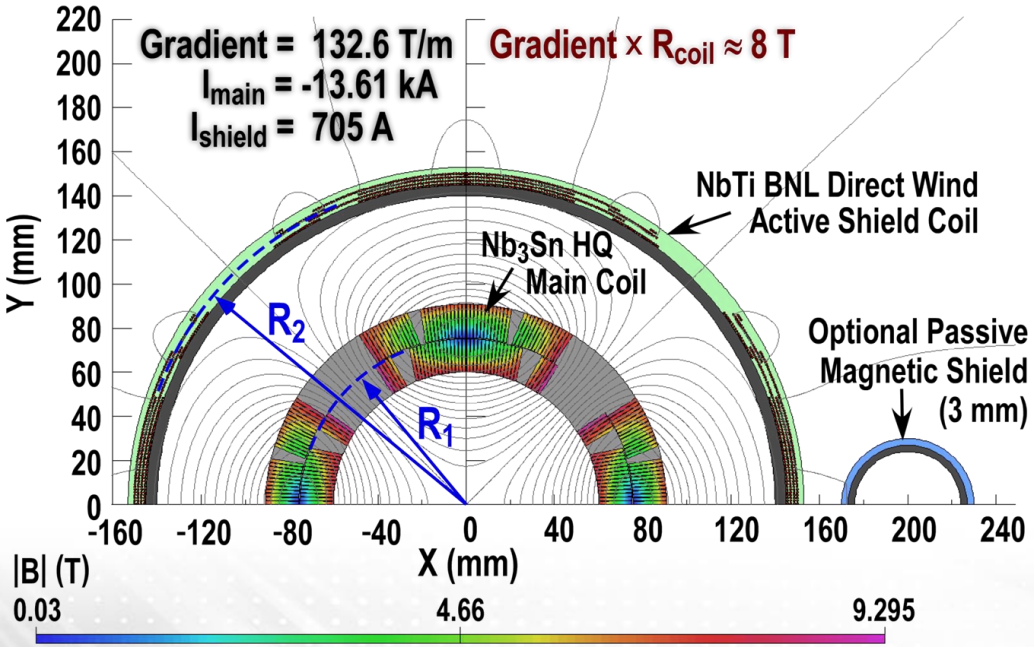
Design and Prototyping of Superconducting EIC – Interaction Region Magnets

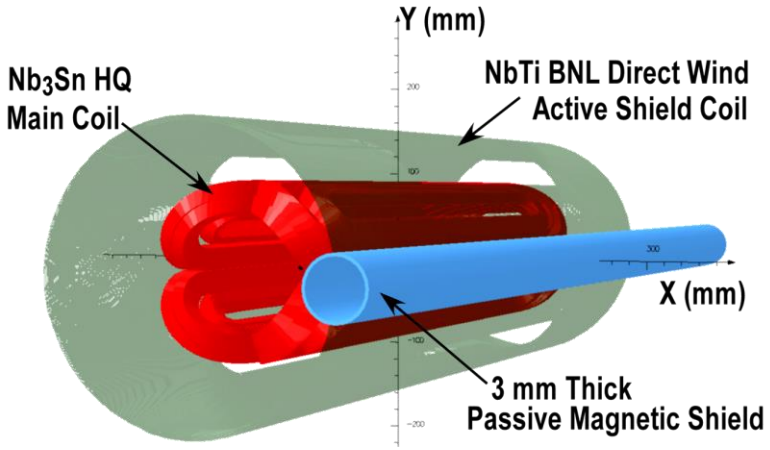
Funding Source	PI	R&D Report Priority #	R&D Panel Priority Rating
FY17	M. Anerella	28	Hi-C

- The panel identified the validation of magnet designs associated with high-acceptance interaction points by prototyping as a key area that is common for all EIC concepts (p. 41)

Overview

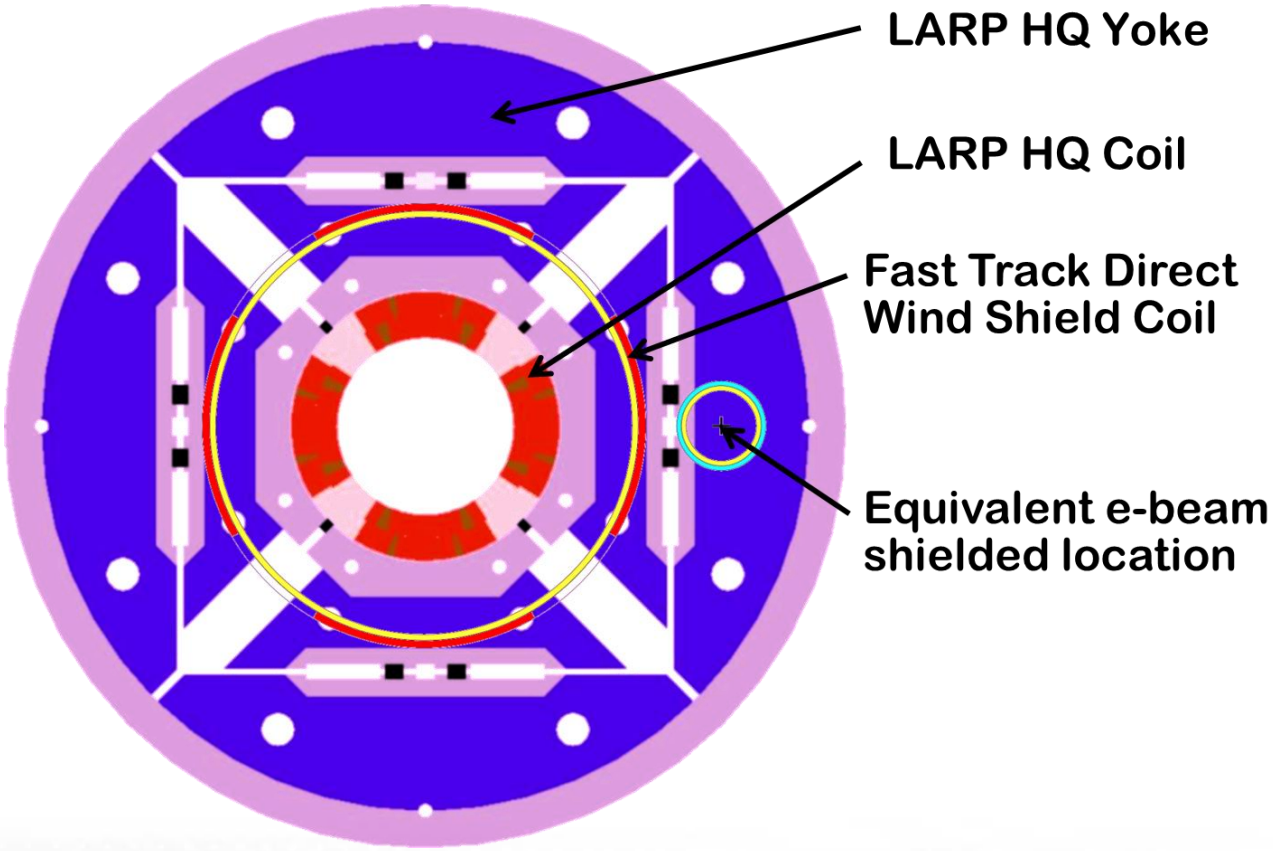
- Hadron IR quads need large apertures & high gradients.
- Must protect e-beam from large external B-fields.
- Solution is to use actively shielded coil geometry [1].





Perspective

Why not use existing, e.g., LHC High Luminosity Upgrade technology/designs?

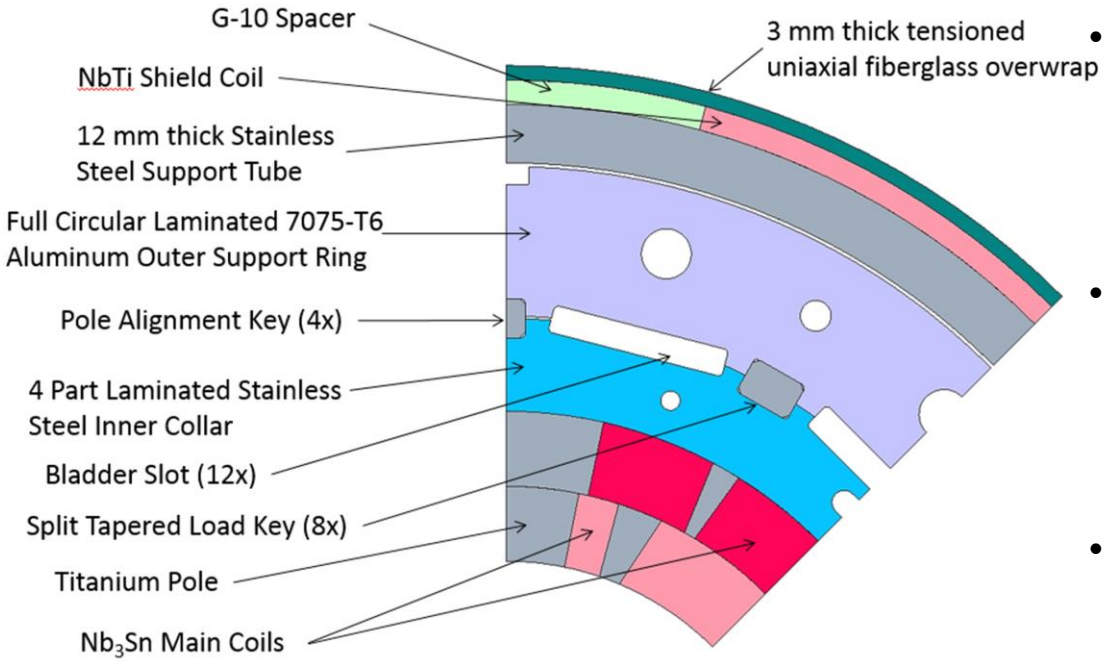


Electron beam cuts through magnetic / mechanical structure

120mm LHC Accelerator Research Program (LARP)
Nb_3Sn High Gradient Quad

Design

Compact mechanical structure "Proof of Principle", i.e., NOT a specific IR solution



Design Parameters	Unit	Value
Clear aperture	mm	120
Gradient	T/m	133
Peak Field	T	9.3
Current (main coil)	kA	13.6
Current (shield coil)	kA	0.7

- Magnet uses tested Nb_3Sn (LARP) 120mm Rutherford main coils inside a (Ø1mm 7 strand NbTi) Direct Wind shield coil.
- In this way we leverage LARP high field Nb_3Sn R&D experience to make a prototype test with minimal risk, investment and time.
- The shield coil provides zero field at the electron beam and reduces the net gradient of the main coil by 7% and also reduces the main coil's net outward Lorentz force (which is unlike a magnetic yoke which would increase the force experienced by the main coil).

Status

BNL

- Magnet, assembly tooling, testing tooling designs are complete
- Assembly tooling fabrication is complete
- Testing tooling fabrication is underway
- 15cm long mockup is underway (details next slide)

LBNL

- 2D model is complete and first results from the 3D model were presented in a video meeting in September (more on following slide)

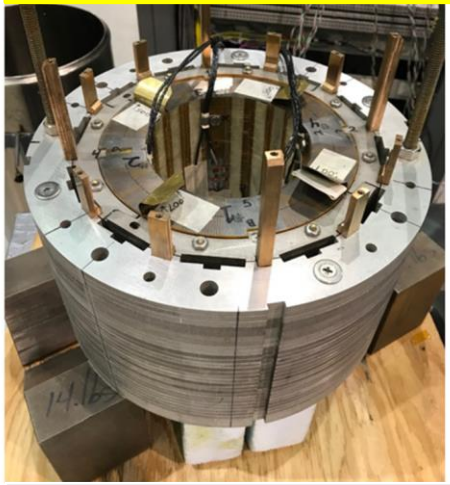
JLab

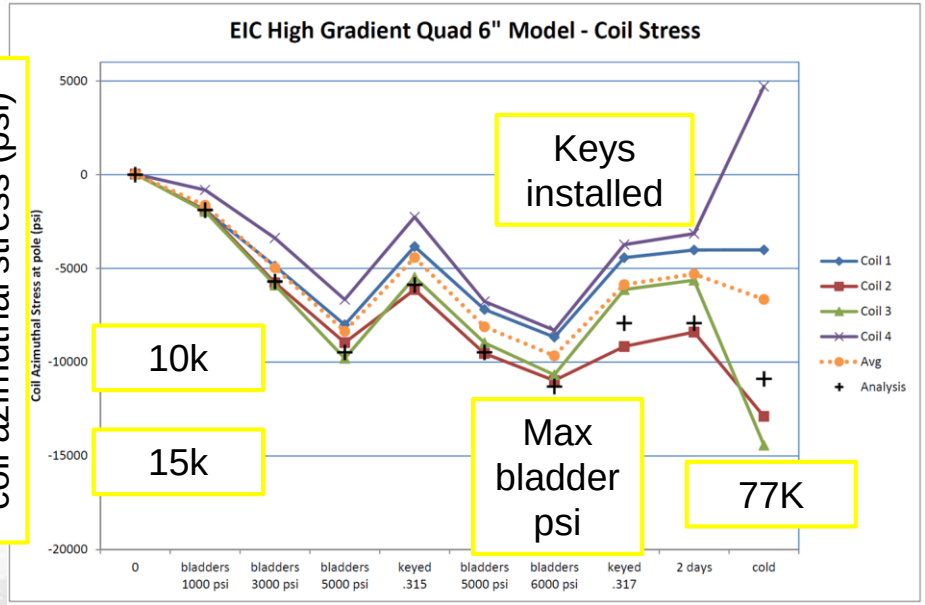
- 1st set of parts fabrication nearly complete, balance of parts fabrication underway (more on following slide)

15cm mockup

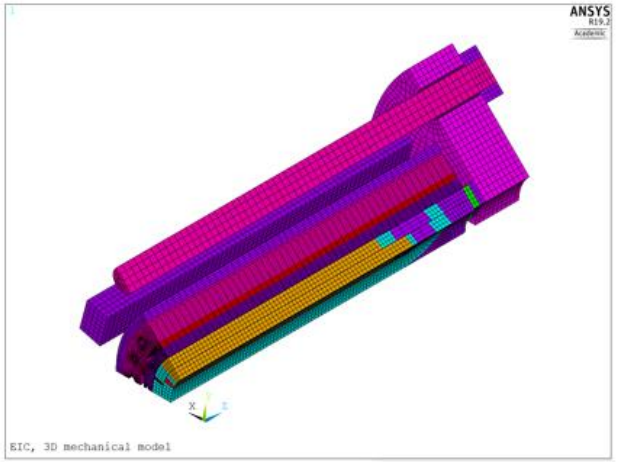
- 2-D experimental confirmation of mechanical structure
- 1st results – good 300K assembly data, ~ ½ of strain gauges failed at 77K
- Short focused R&D effort completed to reliably bond gauges to titanium coil poles
  - Room temperature cure
  - Optimized choice of epoxy
  - Developed improved cleaning & surface preparation
- Ready now for final assembly & thermal cycle
- Additional valuable “lessons learned” – load key opening from bladder pressurization limited by end effects → reliefs introduced at magnet ends to increase assembly efficiency

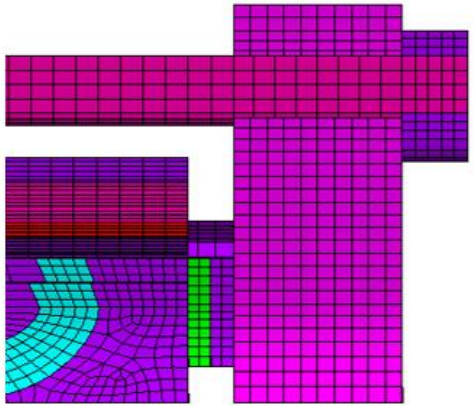
Bladders removed, split tapered load keys installed





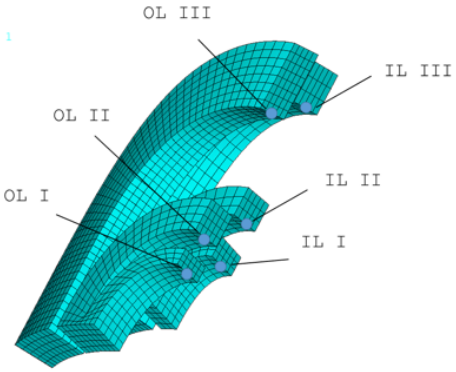
LBNL 3D analysis excerpts

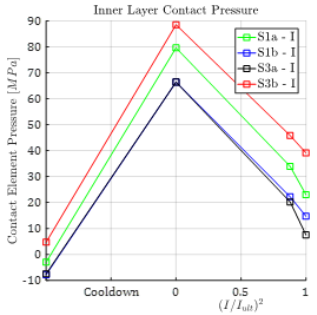


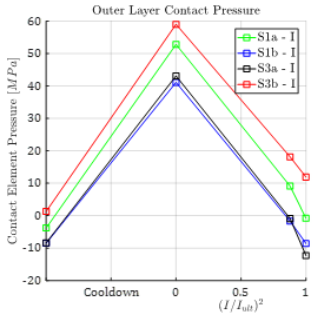


- 3D Model – could help to understand the performances of the long. loading

Courtesy G. Vallone







- How the preload affects the contact in the ends?
- Contact pressure/tension between coil and poles/spacers.

Discussions to continue…

JLab progress

Courtesy T. Michalski

Make (M) vs Buy (B)	NEED BY END OF SEPTEMBER (all else is Oct/Nov)	DWG RELEASED ?	DRAWING NO.	DESCRIPTION	DWG	PART S LIST REQ' D?	PL COMPLE TE?	FABRICATION REFERENCE	QTY REQ'D PER MAGNET	Placed Date	Due Date
B	*	Y	R05901 0009	EIC FAST TRACK COLLAR LAM	D	N			672	8/7/2019	
B	*	Y	R05901 0010	EIC FAST TRACK SUPPORT RING LAM	D	N			272	8/7/2019	
NA			R05901 0011	SHIELD COIL ASSY, SUPPORT TUBE	D	N		COMPLETE	1	BNL	
NA			R05901 0012	END PLATE SPACING BAR ASSY	B	Y		BNL	8	BNL	
M		Y	R05901 0013	END PLATE SPACING BAR	C	N			8	11/4/2019	12/6/2019
NA			R05901 0014	DOWEL PIN, DIA .250 X .50 LONG	B	N		BNL	16	BNL	
			~~R05901 0015~~							N/A	
			~~R05901 0016~~							N/A	
			~~R05901 0017~~							N/A	
M		Y	R05901 0018	BULLETZ-LOAD BLOCK, NON-LEAD END	B	N			4	11/4/2019	12/6/2019
B	*	Y	R05901 0019	LOAD WEDGE PAIR	C	N			8	8/20/2019	
M		Y	R05901 0020	SHIELD COIL-END PLATE CLAMP	C	N			4	11/4/2019	12/6/2019
M	*	Y	R05901 0021	END PLATE, NLE	E	N		COMPLETE	1	9/10/2019	10/11/2019
M		Y	R05901 0022	END PLATE, LE	E	N		COMPLETE	1	9/10/2019	10/11/2019
M	*	Y	R05901 0023	COIL END FORCE SCREW	B	N		COMPLETE	24	8/20/2019	9/30/2019
M		Y	R05901 0024	BULLETZ-LOAD BLOCK, LEAD END	C	N			4	11/4/2019	12/6/2019
M	*	Y	R05901 0025	SHIELD COIL SHIM, NLE, .030 THK	B	N		COMPLETE	8	8/20/2019	
M		Y	R05901 0027	LOCK ROD RETAINER	~~B~~	~~N~~			4	11/4/2019	12/6/2019
M	*	Y	R05901 0028	COLLAR PACK TIE ROD, NLE	B	N		COMPLETE	8	8/6/2018	9/30/2019
M		Y	R05901 0029	SHIELD COIL CENTERING KEY (VERTICAL T	C	N			4	11/4/2019	12/6/2019
M		Y	R05901 0030	SUPPORT RING TIE ROD	B	N			4	11/4/2019	12/6/2019
M		Y	R05901 0031	Z-LOAD TIE ROD	C	N			4	11/4/2019	12/6/2019
M		Y	R05901 0032	SHIELD COIL SHIM, LE, .030 THK	B	N			8	11/4/2019	12/6/2019
M	*	Y	R05901 0033	COLLAR PACK TIE ROD, LE	B	N		COMPLETE	16	8/6/2018	9/30/2019
M	*	Y	R05901 0034	COLLAR PACK LOCK ROD, LE	B	N		COMPLETE	8	8/6/2018	9/30/2019
M	*	Y	R05901 0035	COLLAR PACK LOCK ROD, CTR	B	N		COMPLETE	12	8/6/2018	9/30/2019
M	*	Y	R05901 0037	COLLAR PACK TIE ROD, CTR	B	N		COMPLETE	24	8/6/2018	9/30/2019
M		Y	R05901 0038	PIZZABOX SUPPORT STRUT, HALF 1	C	N			4	11/4/2019	12/13/2019
M		Y	R05901 0039	PIZZABOX SUPPORT STRUT, HALF 2	C	N			4	11/4/2019	12/13/2019
M		Y	R05901 0043	BASEPLATE	D	N			1	11/4/2019	12/13/2019
M		Y	R05901 0044	COVER PLATE, RED LEAD	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0045	COVER PLATE, BLUE LEAD	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0046	COVER PLATE, QUADRANT 2	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0047	COVER PLATE, QUADRANT 3	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0048	LEAD QUADRANT RED	D	N			1	11/4/2019	12/13/2019
M		Y	R05901 0049	LEAD QUADRANT BLUE	D	N			1	11/4/2019	12/13/2019
M		Y	R05901 0050	LEAD QUADRANT 2	D	N			1	11/4/2019	12/13/2019
M		Y	R05901 0051	LEAD QUADRANT 3	D	N			1	11/4/2019	12/13/2019
M		Y	R05901 0052	SOLDER BLOCK FILLER,TYPE 1	B	N			2	11/4/2019	12/13/2019
M		Y	R05901 0053	SOLDER BLOCK FILLER TYPE 2	B	N			1	11/4/2019	12/13/2019
M		Y	R05901 0054	RADIUS BLOCK, QUADRANT RED	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0055	RADIUS BLOCK, QUADRANT BLUE	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0056	RADIUS BLOCK, QUADRANT 2	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0057	RADIUS BLOCK, QUADRANT 3	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0058	LEAD SPACER J	C	N			1	11/4/2019	12/13/2019
M		Y	R05901 0059	LEAD SPACER Q2L1	C	N			1	11/4/2019	12/13/2019
B		Y	R05901 0065	Z-LOAD HEX NUT 1.50-12 UNF A286SS	B	N			9	11/4/2019	12/6/2019
M	*	Y	R05901 0066	COLLAR PACK ALIGNMENT KEY, NLE	B	N		COMPLETE	4	8/6/2018	9/30/2019
			~~R05901 0067~~							N/A	
M	*	Y	R05901 0068	COLLAR PACK ALIGNMENT KEY, CTR	B	N		COMPLETE	12	8/6/2018	9/30/2019
M	*	Y	R05901 0069	COLLAR PACK ALIGNMENT KEY, LE	B	N		COMPLETE	4	8/6/2018	9/30/2019
M	*	Y	R05901 0070	COLLAR PACK ALIGNMENT KEY, LE FAR	B	N		COMPLETE	4	8/6/2018	9/30/2019
B	*	Y	R05901 0071	END COLLAR LAMINATION	E	N		COMPLETE	432	8/7/2019	
B	*	Y	R05901 0072	END SUPPORT RING LAMINATION	D	N		COMPLETE	5	8/7/2019	
M	*	Y	R05901 0073	COLLAR PACK LOCK ROD, NLE ASSY	B	N		COMPLETE	4	8/6/2018	9/30/2019

Managing the bulk of parts fab:

- 1st deliveries due 10/19
- Balance requested 12/19

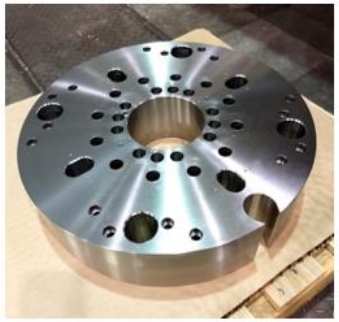
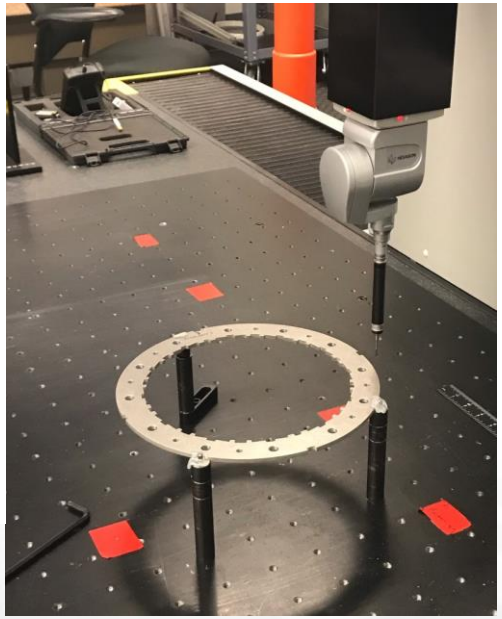


Figure 1: End Plate, Non-Lead End

Figure 2: Misc. components, keys, rods, shims, end load bolts



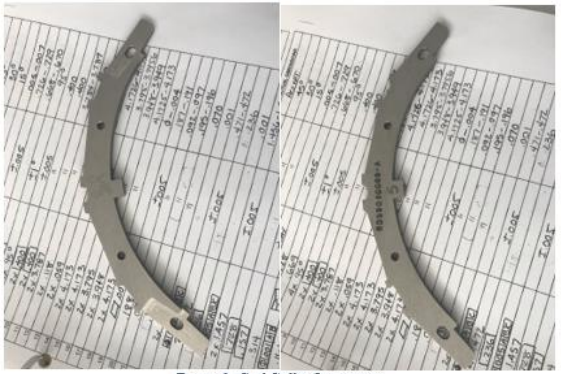


Figure 3: Coil Collar Lamination

Budget

BNL

	FY 2018	FY 2019	Total
a) Funds allocated	$1,140,000	$1,140,000	$2,280,000
b) Actual costs to date	$128,638	$496,892	$625,530

LBNL

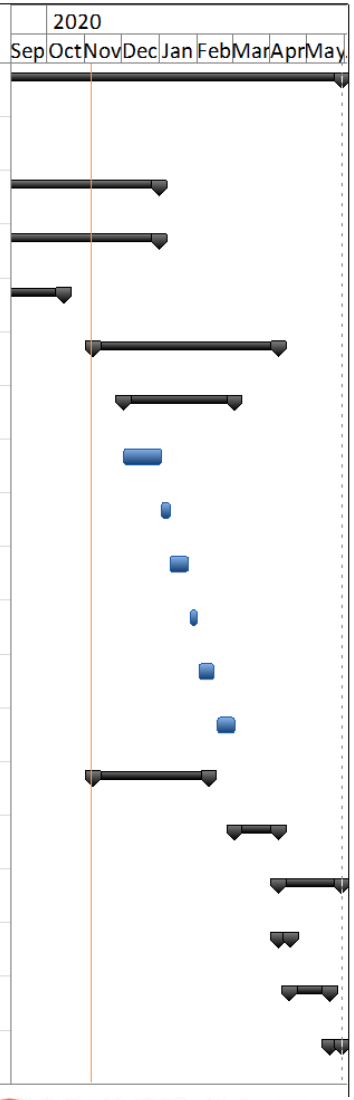
	FY 2018	FY 2019	Total
a) Funds allocated	$100,000	$100,000	$200,000
b) Actual costs to date	$ 25,031	$ 69,027	$ 94,238

JLab

	FY 2018	FY 2019	Total
a) Funds allocated	$218.0k	$218.0k	$436.0k
b) Actual costs to date	$163.85k	$0.0k	$163.85k

Working Schedule

ID	WBS	% Complete	Task Name	Work	Duration	Start	Finish
1	**1**	**64%**	**High Gradient Actively Shielded Quadrupole**	**8,124.22 ...**	**457 days**	**Wed 8/1/18**	**Fri 5/29/20**
2	**1.1**	**94%**	**Design**	**2,262.85 ...**	**248 days**	**Wed 8/1/18**	**Mon 7/29/19**
10	**1.2**	**70%**	**Parts Fabrication**	**431.2 hrs**	**332 days**	**Wed 8/29/18**	**Tue 12/31/19**
17	**1.3**	**63%**	**Installation**	**320 hrs**	**312 days**	**Thu 9/27/18**	**Tue 12/31/19**
22	**1.4**	**100%**	**receive/inspect HQ coils at LBNL**	**590 hrs**	**259 days**	**Mon 10/1/18**	**Mon 10/14/19**
25	**1.5**	**0%**	**Assembly**	**2,504 hrs**	**100 days**	**Fri 11/8/19**	**Tue 4/7/20**
26	**1.5.1**	**0%**	**main quad**	**1,320 hrs**	**60 days**	**Tue 12/3/19**	**Mon 3/2/20**
27	1.5.1.1	0%	install strain gauges	0 hrs	20 days	Tue 12/3/19	Thu 1/2/20
28	1.5.1.2	0%	collar test assembly	0 hrs	5 days	Fri 1/3/20	Thu 1/9/20
29	1.5.1.3	0%	assemble in structure	0 hrs	10 days	Fri 1/10/20	Fri 1/24/20
30	1.5.1.4	0%	diassemble	0 hrs	5 days	Mon 1/27/20	Fri 1/31/20
31	1.5.1.5	0%	reassemble coils / install collars	0 hrs	10 days	Mon 2/3/20	Fri 2/14/20
32	1.5.1.6	0%	assemble structure	0 hrs	10 days	Tue 2/18/20	Mon 3/2/20
33	**1.5.2**	**0%**	**shield quad**	**760 hrs**	**60 days**	**Fri 11/8/19**	**Mon 2/10/20**
65	**1.5.3**	**0%**	**magnet assembly**	**424 hrs**	**26 days**	**Tue 3/3/20**	**Tue 4/7/20**
72	**1.6**	**0%**	**Magnet Test**	**1,102.17 ...**	**38 days**	**Wed 4/8/20**	**Fri 5/29/20**
73	**1.6.1**	**0%**	**prepare for test**	**86.4 hrs**	**8 days**	**Wed 4/8/20**	**Fri 4/17/20**
80	**1.6.2**	**0%**	**Cold Test**	**710 hrs**	**23 days**	**Fri 4/17/20**	**Tue 5/19/20**
91	**1.6.3**	**0%**	**breakdown test**	**96 hrs**	**8 days**	**Wed 5/20/20**	**Fri 5/29/20**



Testing schedule may shift to avoid AUP testing conflict