LHC-type C0 Quadrupoles

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  - Quench performance
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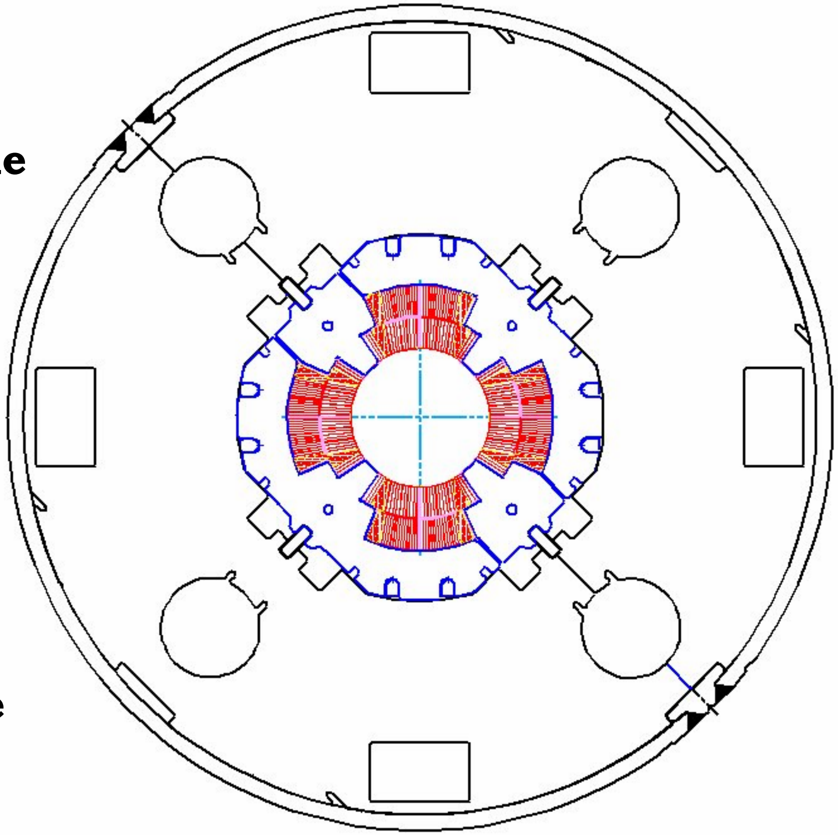
C0 Requirements

❖ **C0 requires quadrupoles of LHC type from Q1 through Q5**

Magnet	Nominal Gradient (T/m)	Magnetic Length (m)	Magnetic Center (m from IP)	Slot Length (m)
Q1	170	2.41	14.263	3.520
Q2	170	4.43	18.749	5.476
Q3	170	2.41	24.661	3.520
Q4	170	2.01	65.115	2.974
Q5	170	1.37	86.911	2.441

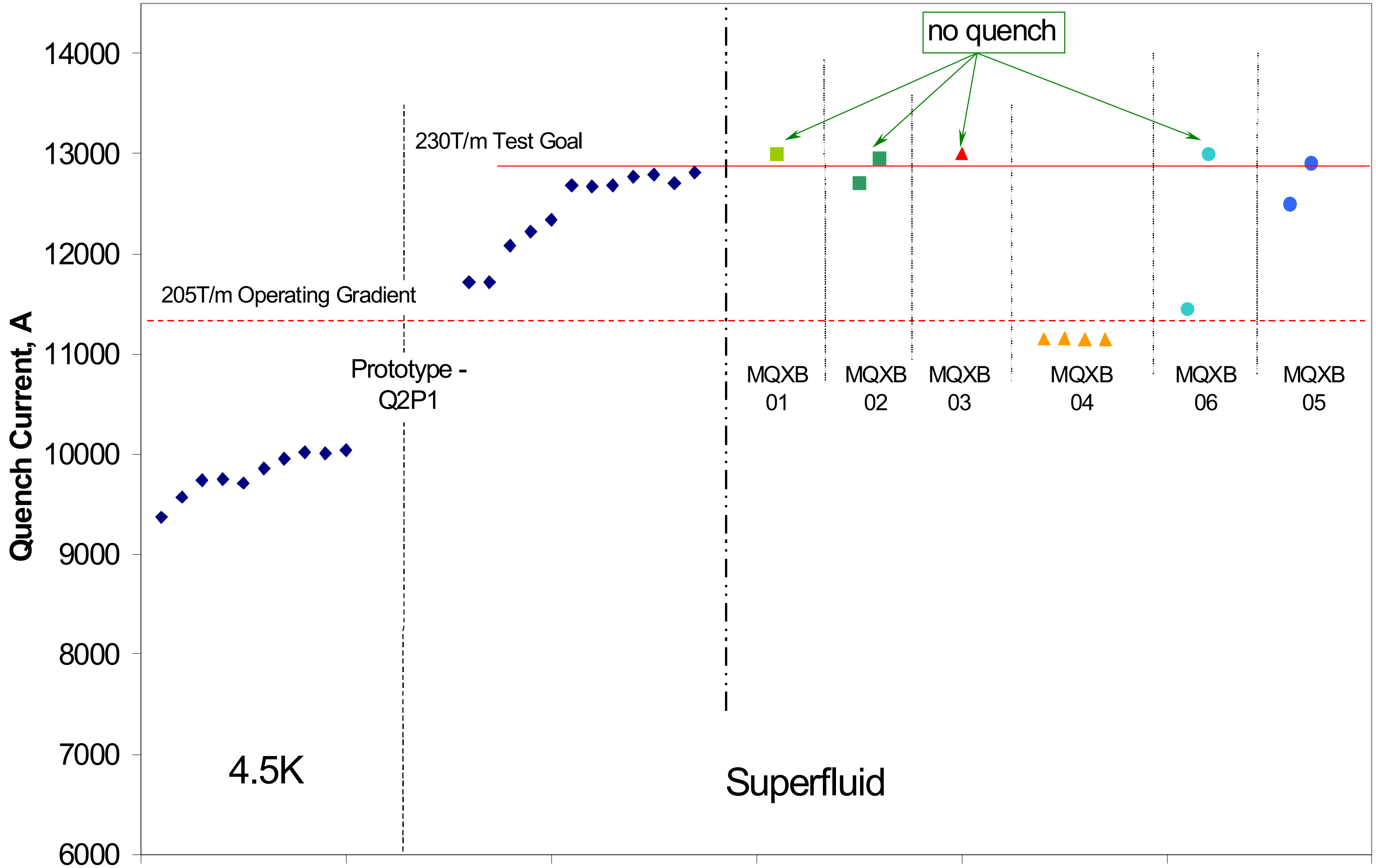
LHC IR Quadrupoles

- **LHC IR Quadrupole Magnet Features**
  - **NbTi Coil, 70 mm bore diameter**
  - **Nitronic-40 collar structure which provides the entire pre-stress to the coil assembly**
  - **400 mm OD yoke; 416 mm OD**
  - **Magnetic Length = 5.5 m**
  - **Mechanical Length = 5.8 m**
  - **2K operating temperature**
  - **205 T/m collision gradient**
  - **215 T/m maximum gradient**
  - **250 T/m short sample**
  - **Cryostat designed to accommodate 490 mm KEK magnet and external heat exchanger for LHC IR energy deposition**



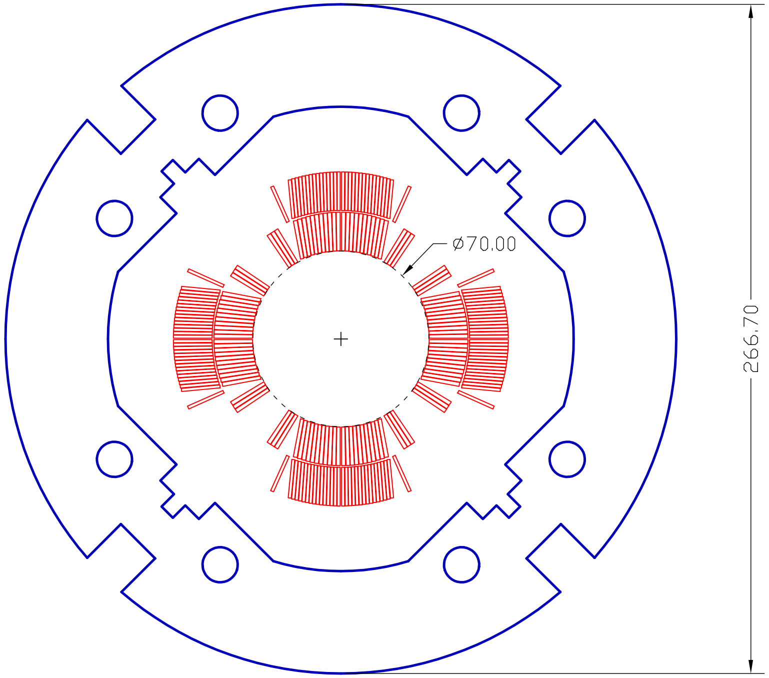
LHC IR Quadrupoles

❖ Quench Performance



C0 Quadrupoles

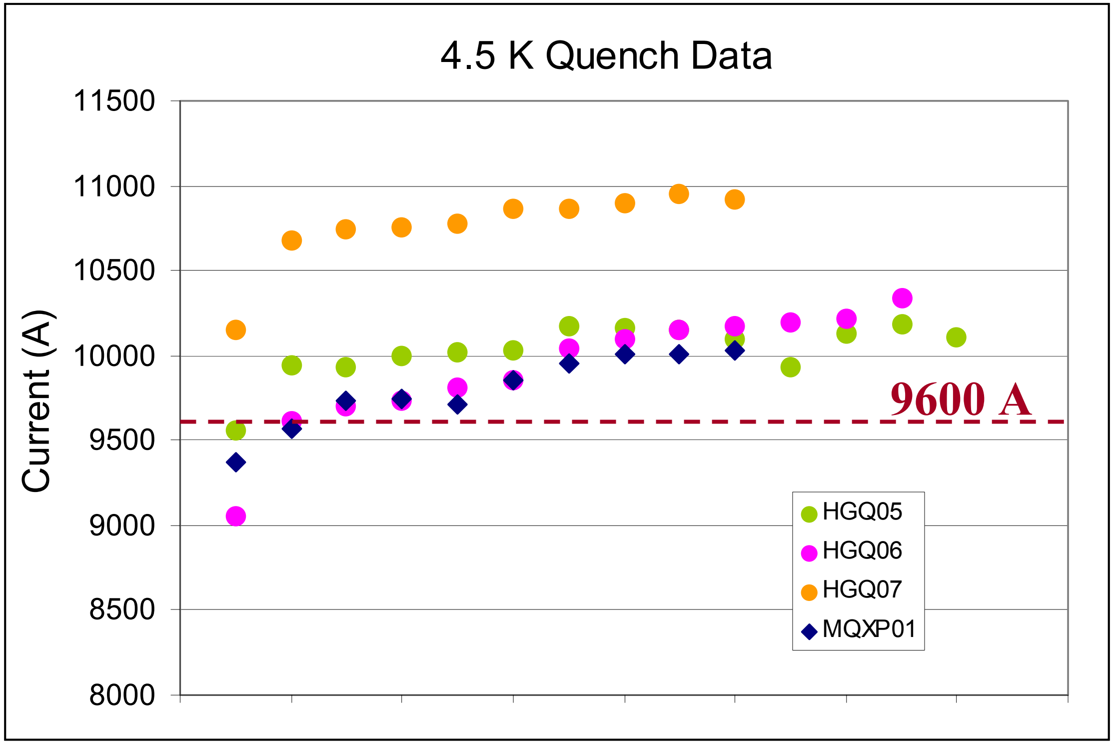
- **LHC IR quadrupole design was optimized for C0**
  - **Coil cross-section and mechanical support in the straight section will be the same**
  - **Magnet operating temperature will be 4.5 K**
  - **C0 operating gradient is 20% lower than the LHC requirement, so Iron yoke has been re-optimized and the outside diameter reduced to produce a more compact design, with acceptable harmonics**



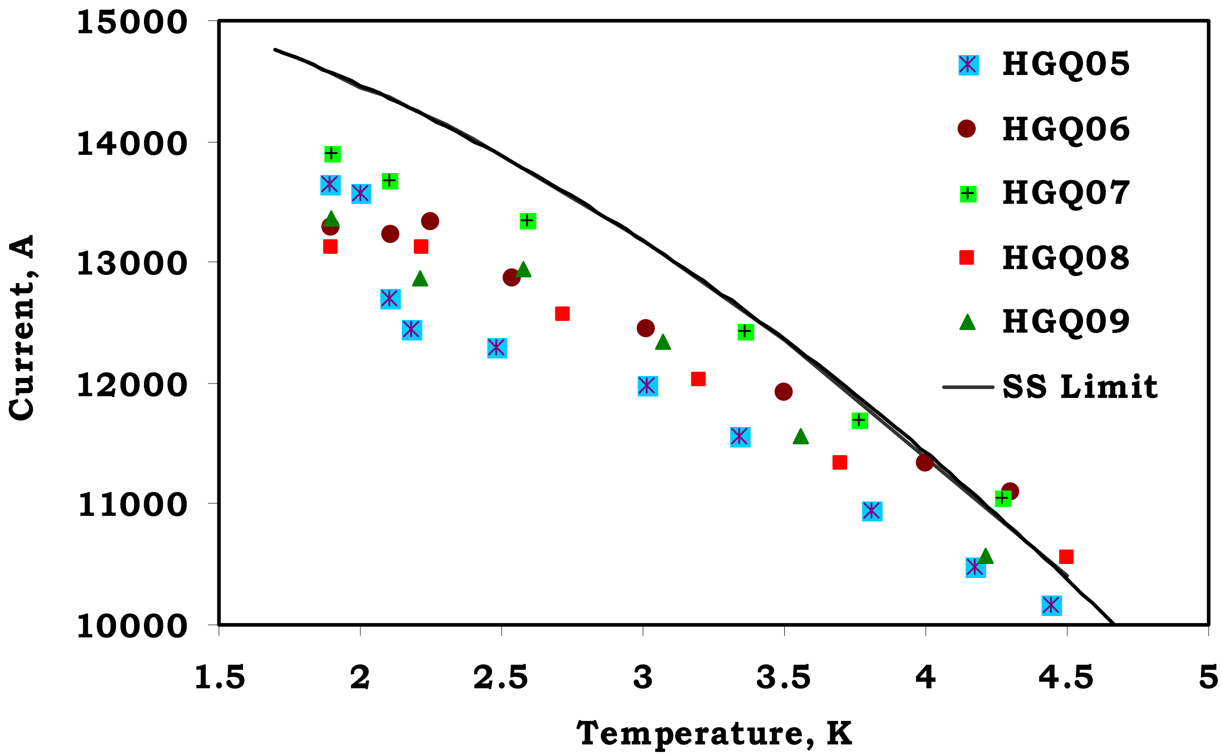
C0 Quadrupoles: Expected Performance

BTEV C0

- **Quench performance of LHC IR model magnets and prototype exceeded C0 requirements at 4.5K**
  - o **The variations of the maximum current reached during training is due to the variations in the critical current density of NbTi strands used in these models**
  - o **No retraining observed**



❖ Temperature Dependence

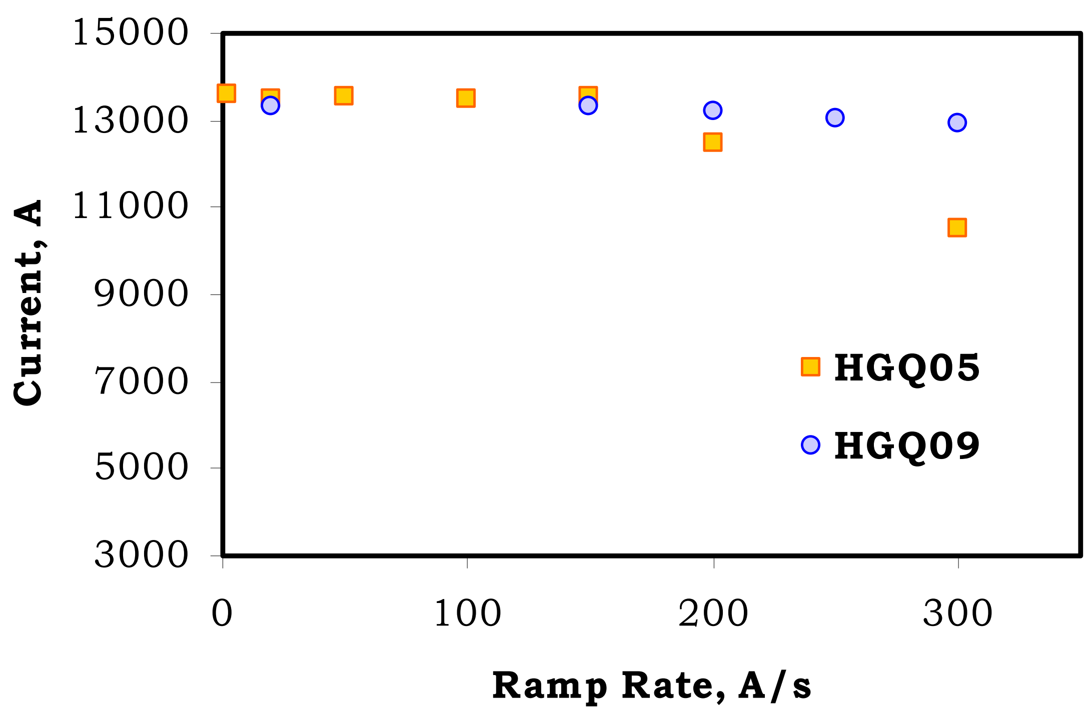


Note: Solid line shows the short sample limit for this magnet design calculated based on the SSC strand specifications.

C0 Quadrupoles: Expected Performance

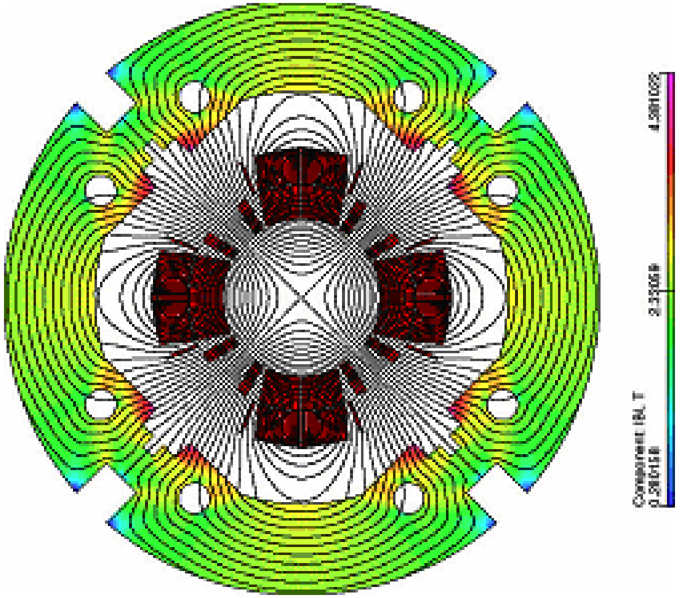
❖ Ramp Rate Dependence

- **Dependence of magnet quench current at 1.9 K vs. the current ramp rate for HGQ05 and HGQ09 fabricated using the optimized coil curing cycle is shown. Similar performance is expected for C0 quadrupoles at 4.5 K**



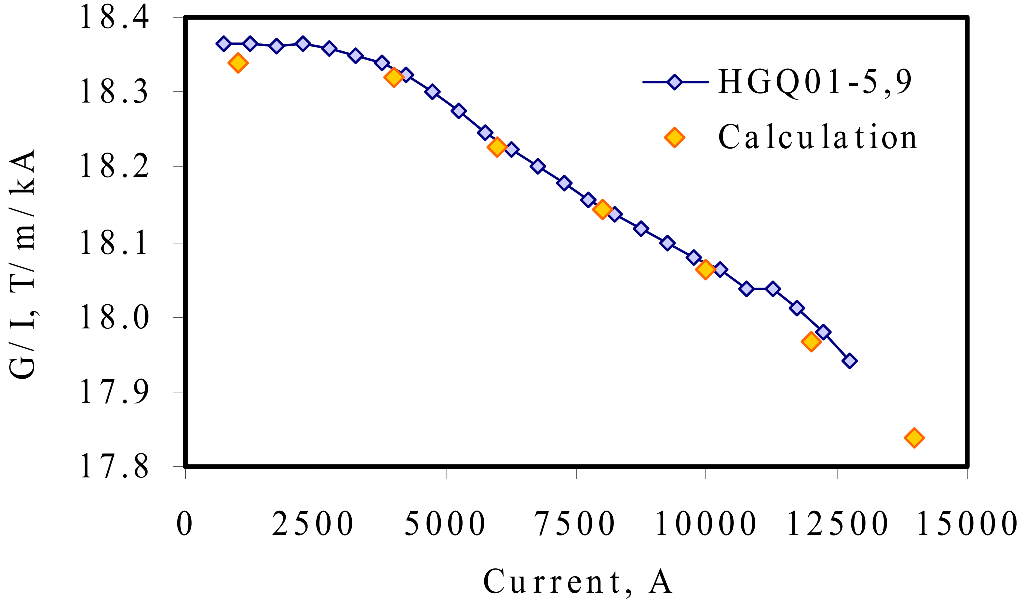
Magnet Field Quality

- C0 quadrupoles should have similar field quality as LHC quadrupoles since the collared coil assembly which determines the basic field properties is kept the same
  - One modification that affects the field quality was the reduction of Iron Yoke OD from 400 mm to 267 mm.
    - Iron yoke cross-section was optimized taking into account the iron saturation effects while providing the channels for power and instrumentation cables as well as for helium flow



Magnet Transfer Function

- **Good correlation between measured and calculated data for HGQ short models**
  - **The reduction of the magnet transfer function at high currents is caused by iron saturation**
  - **At an operating current of 10 kA, the nominal gradient is about 180 T/m**
  - **Transfer function for C0 quadrupole design could be calculated to high accuracy and would provide similar good agreement**



Field Harmonics

- Comparison of the field quality of HGQ models with the Low Beta Quadrupoles showed that HGQ is moderately better.

		LBQ						HGQ	
		132"		232"		54"		5.5 m	
	n	average	variance	average	variance	average	variance	average	variance
normal	***b2***	0.61	1.53	-0.55	1.95	0.62	1.03	0.90	0.73
	b3	-0.44	1.01	0.02	0.89	0.21	0.40	-0.04	0.31
	b4	-0.22	0.32	0.28	0.23	0.29	0.50	-0.11	0.61
	b5	-2.42	1.08	-2.01	0.85	-3.10	1.44	0.09	1.08
	b6	0.03	0.36	0.01	0.17	0.05	0.26	0.06	0.31
	b7	-0.04	0.18	-0.06	0.19	0.05	0.11	-0.06	0.09
	b8	-0.03	0.19	0.04	0.12	0.08	0.19	-0.03	0.12
	b9	-0.90	0.20	-0.68	0.11	-0.75	0.17	-0.36	0.28
	b10	-0.04	0.23	0.06	0.10	0.03	0.14		
	b11	0.03	0.25	-0.01	0.06	0.01	0.25		
	b12	0.14	0.25	-0.08	0.16	-0.12	0.51		
	b13	1.30	0.21	1.36	0.24	1.21	0.17	-1.81	0.21
skew	***a2***	0.30	2.59	0.12	3.17	-0.63	2.65	0.32	0.74
	a3	-0.47	0.98	-0.50	0.86	0.13	0.95	-0.43	1.53
	a4	-0.49	0.42	0.35	0.66	-0.31	0.68	-0.28	0.87
	a5	0.08	0.42	0.10	0.24	-0.03	0.59	-0.38	0.36
	a6	0.17	0.26	-0.08	0.39	0.01	0.29	0.24	0.35
	a7	0.06	0.21	-0.07	0.14	0.02	0.15	0.02	0.21
	a8	-0.04	0.20	0.08	0.11	0.05	0.13	0.03	0.14
	a9	0.16	0.20	0.14	0.20	0.17	0.10	-0.02	0.06
	a10	0.06	0.25	-0.04	0.09	-0.07	0.19		
	a11	0.07	0.19	-0.12	0.11	-0.07	0.21		
	a12	-0.04	0.21	-0.11	0.17	-0.19	0.38		
	a13	-0.58	0.26	-0.26	0.20	-0.22	0.87		

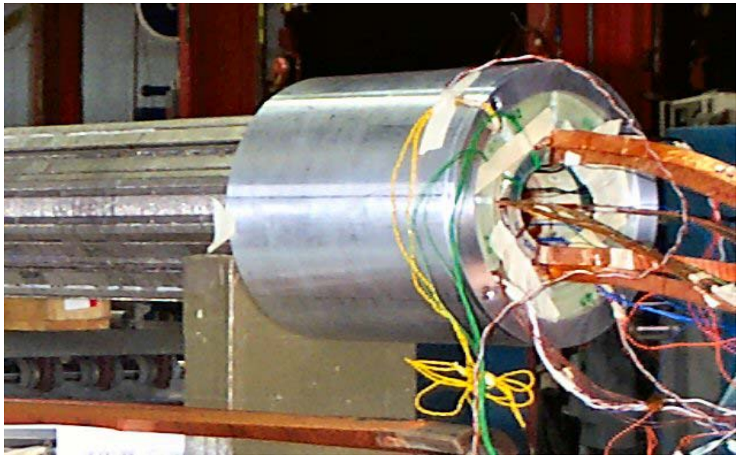
Note: HGQ harmonics were calculated with the TeV reference radius of 25.4 mm and weighted end-body average is calculated for a 5.5 m cold mass.

C0 Quadrupoles: Design Changes

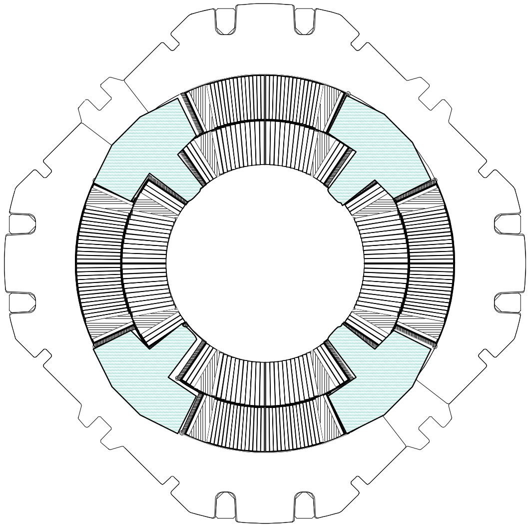
- **The Q1-Q5 magnets are a modest redesign of the LHC quadrupoles**
  - ***Reducing the iron yoke OD***
  - ***Reducing the overall magnet OD***
  - **Mechanical support of the ends**
  - **Axial Restraint**
  - **Quadrant splice design**
  - **Bus Design / Expansion Loops**
  - **Reducing the overall diameter of the cryostat**
  - **Cryostat interfaces**

C0 IR Quadrupoles: Design Changes

- **End-Design**
  - Due to the reduction in the iron yoke diameter, the mechanical support of the ends of the coil might have to be changed
  - The current end-design could still be implemented with some changes to iron yoke OD and is currently being investigated



  - Full-round collars could be another solution, as was used in early HGQ model magnets. Note that these are typically used in other superconducting magnets (LHC Arc Dipole, for example)



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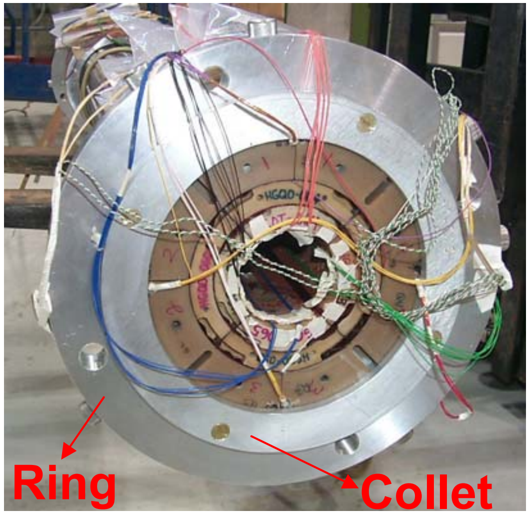
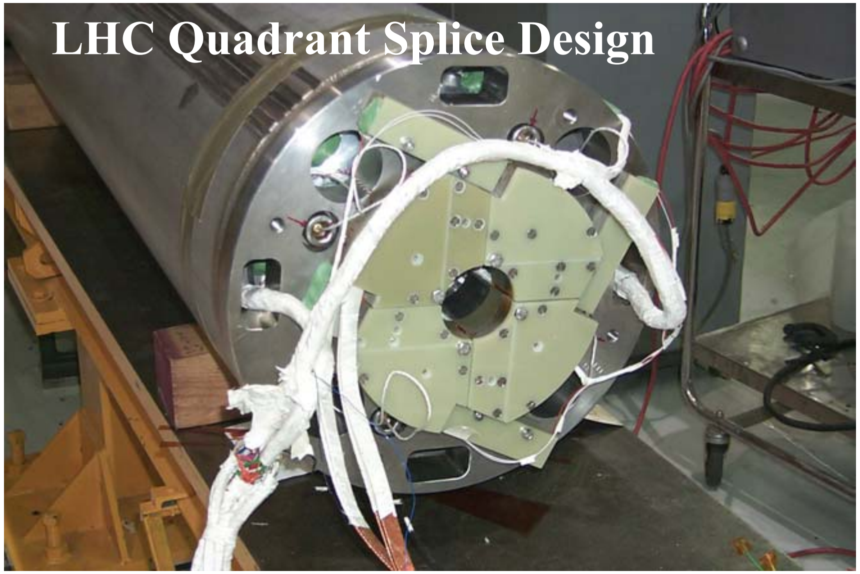
Axial Restraint

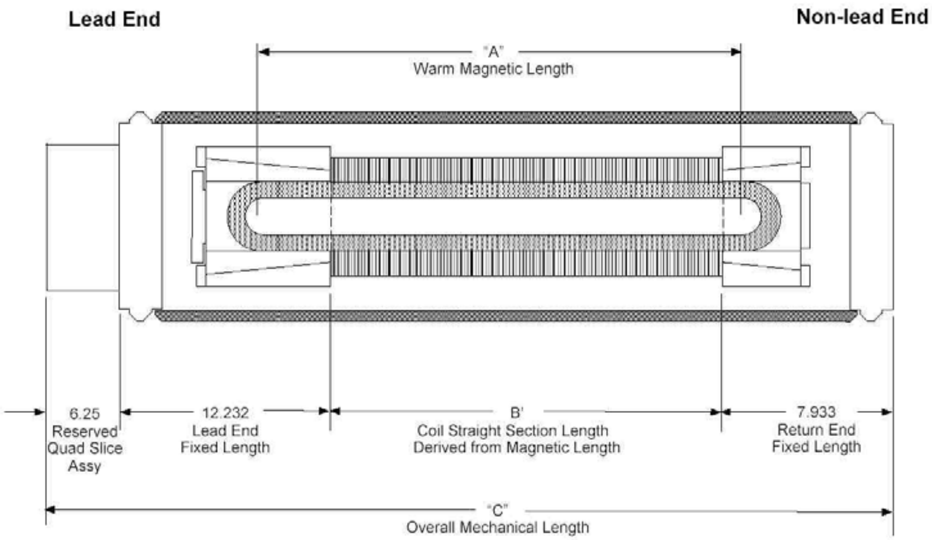
- In the current LHC design, the ends of the cold mass are defined by steel end plates, which are used to anchor the collared coil longitudinally
- It has been shown in the LHC model magnet program that the quench performance does not seem to depend on the axial restraint.
- The benefit of having the axial restraint is that it would fix the coil lengths with respect to the end-plates and this will ensure a good repeatability of magnetic lengths
- If the collet design is retained, we have to change the anchor design to account for the reduced yoke OD – one solution is to bolt directly to the collet instead of having the ring
- If full-round collars are used, then the axial restraint could be applied though radial interference between yoke and the full-round collars in the end



C0 IR Quadrupoles: Design Changes

- **Quadrant Splice Design**
  - **The reduced overall diameter of the magnet impacts the quadrant splice design which mounts to the lead end plate**
  - **LHC design has the splices in a plane perpendicular to the beam axis. We are assuming for C0 that the splices will be made parallel to the beam axis**



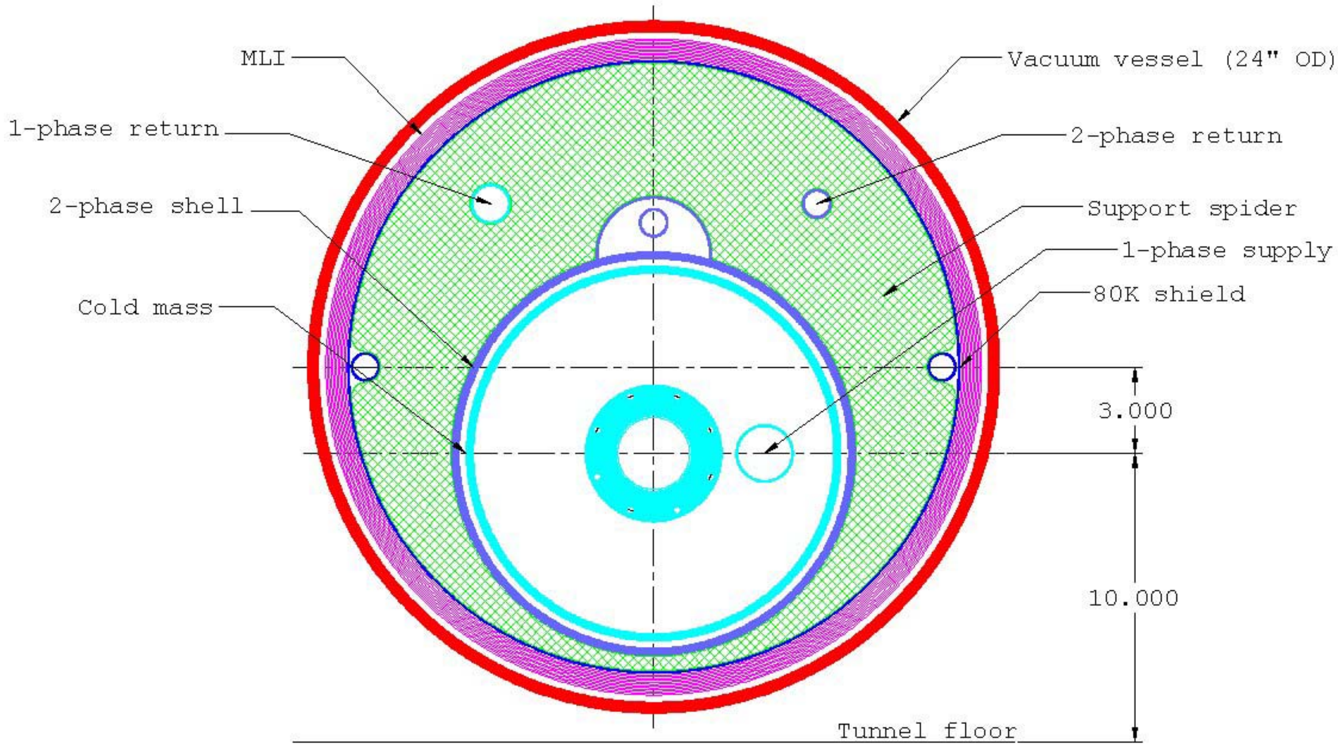


C0 IR Quadrupoles: Design Changes

- **Bus Design – C0 bus design is expected to be very similar to the LHC bus, however given the magnet diameter we may need to explore ways to make it more flexible**
  - **Once the bus design is fixed, details of the bus slots in the yoke can be determined**
- **Splice Length in the Interconnects – The allotted length for splice in the TeV interconnects is about 3.5 in compared to 6 in splice length for LHC type cable**
  - **The bus design would eventually determine the required lengths and space for splices in the interconnects**
- **Expansion Loops – The design for the expansion loops would also depend on the bus design. One possibility is to loop around the quadrant splice block**

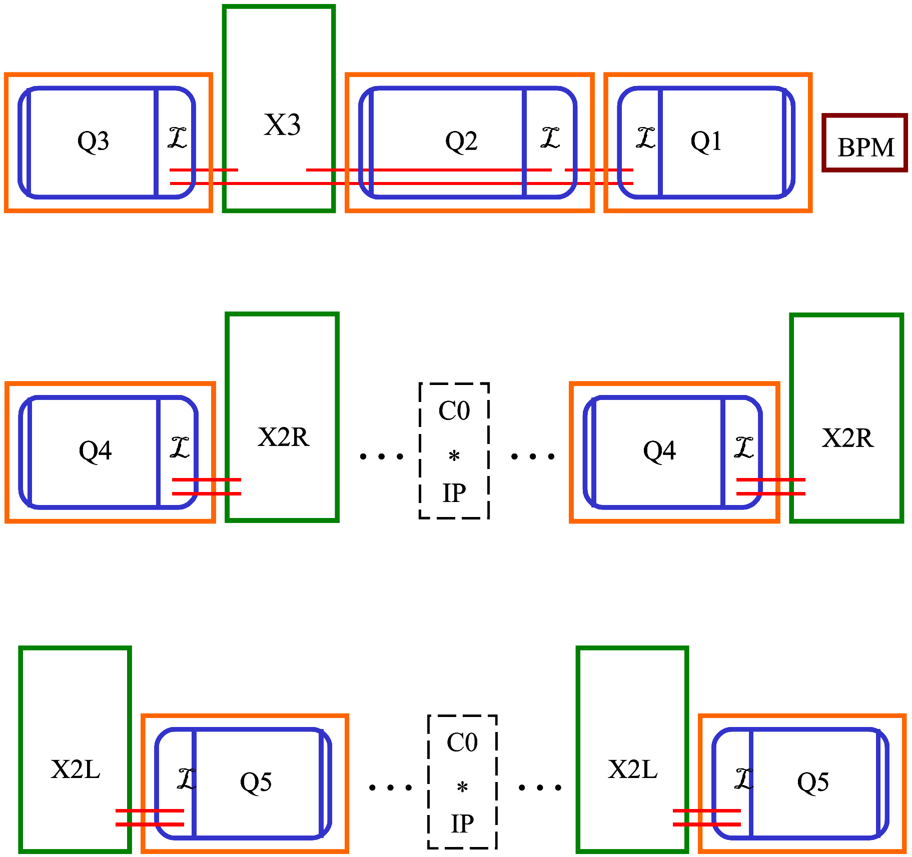
Cryostat Requirements: Overall Diameter

- The criteria for the new C0 quadrupoles is accommodating the Tevatron beam height off the tunnel floor, without requiring any further civil construction in the tunnel
  - With the reduced magnet diameter, it appears possible to position the magnet beam line correctly in the tunnel



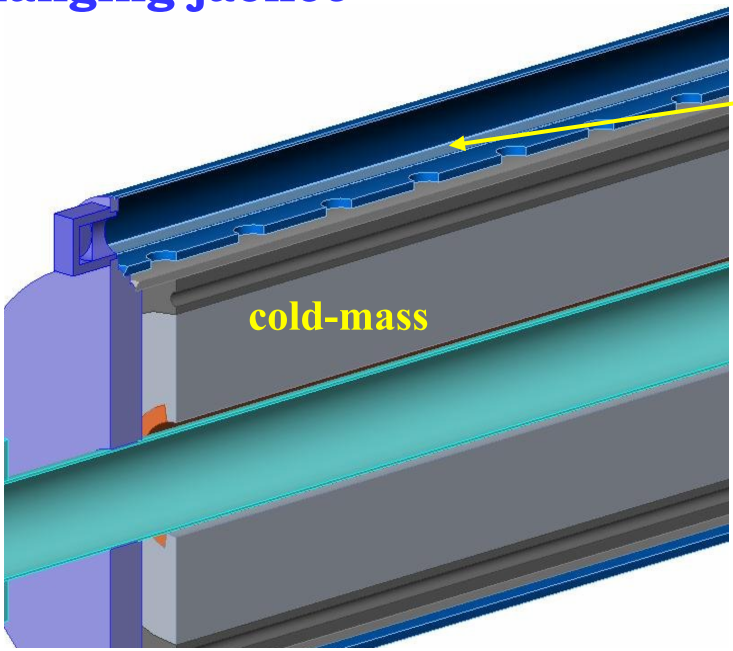
Cryostat Requirements: Interfaces

- **The magnets have a constraint that the end not attached to X2 and X3 spools must be compatible with a standard Tevatron arc interface**
  - **The cryostat must also accommodate any through piping, bus or instrumentation required by the Tevatron string**



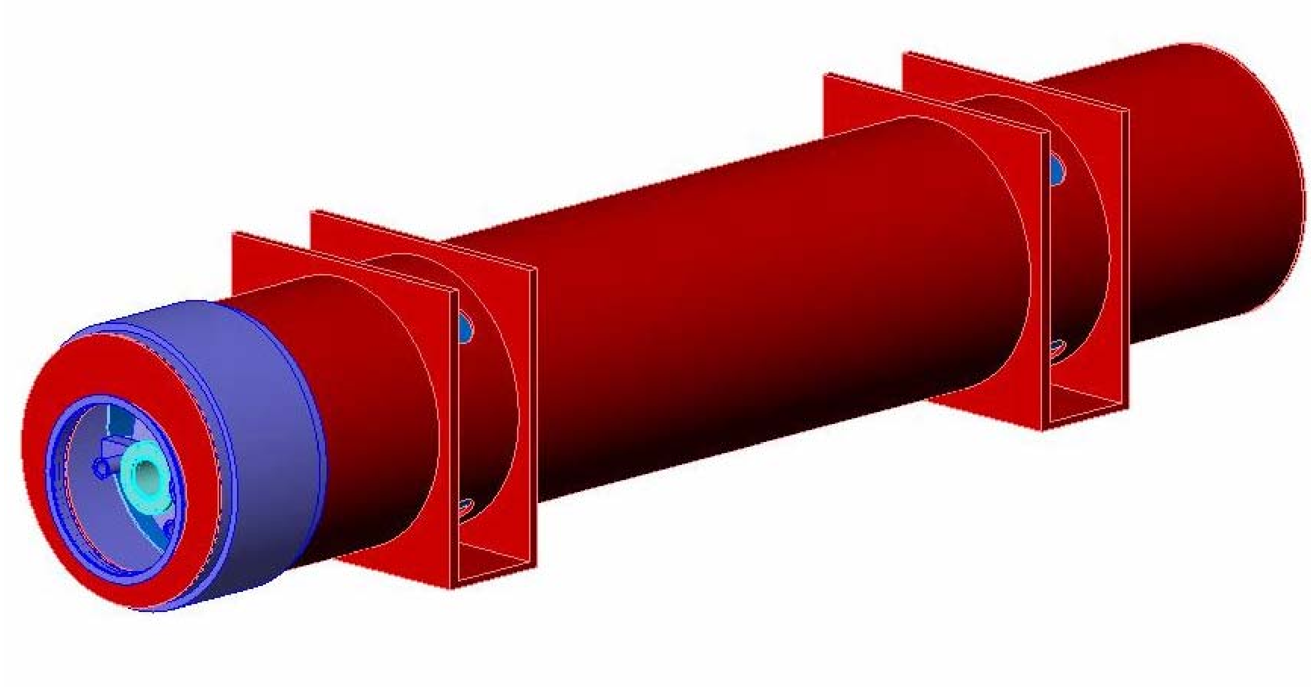
Cryogenic Specifications

- **Interconnect Configuration**
  - **Q1, Q2 & Q3 → Tevatron cryo + single phase, two phase and shield returns**
  - **Q4 & Q5 → Tevatron (at least one end)**
- **Similar to the existing Tevatron LBQs installed at B0 and D0, it is envisioned that the C0 quadrupole magnet will be cooled by a twp phase heat exchanging jacket**



Cryostat Design

- **The preliminary concept for cryostat assembly has been developed**
  - **Each magnet will be supported at two locations along the length, with the internal and external supports at the same location**



Pre-Production R&D

- **HGQ-09 Cold tests**
  - **Cold tests on HGQ-09 could potentially include modified mechanical support of the ends and new iron yoke design**

- **Quadrant splice design needs to be developed and a mock-up will be fabricated as a check**

- **Bus mock-up followed by Expansion Loop mock-up to verify the designs**

Summary

- C0 quadrupoles are a modest redesign of an already proven LHC IR quadrupoles
  - The expected quench performance of these quadrupoles based on LHC model magnet tests satisfy C0 requirements
- Design changes include reducing yoke OD, the magnet OD, quadrant splice design, and may include mechanical support to the ends and axial restraint
- LHC model magnet, HGQ-09 will be cold tested to understand the afore mentioned design changes
- Cryostat requirements have been identified and a preliminary conceptual design exists