Compact Superconducting Magnet Solution for the 20 mr Crossing Angle Final Focus

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Message: Progress continues on the compact superconducting magnets for the 20 mr crossing angle ILC IR layout. A QD0 magnetic prototype (QT), produced using the BNL direct wind technique, has very good integral field harmonics and quench performance. 3D CAD modeling of the near IR region is also in progress.

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Presentation Outline:

- Review the 20 mr crossing angle layout.
- Report on progress made developing the cryostat and cryogenic feed concepts in a 3D CAD model model for the magnets closest to the IP, QD0, QEX and the Anti-solenoid.
- Report recent test results for a QD0 magnetic prototype, QT, produced via the direct wind technique, that more than satisfies the presently proposed magnet design requirements.

ILC Straw Design Layout for 20 mr Crossing Angle Final Focus Optics.

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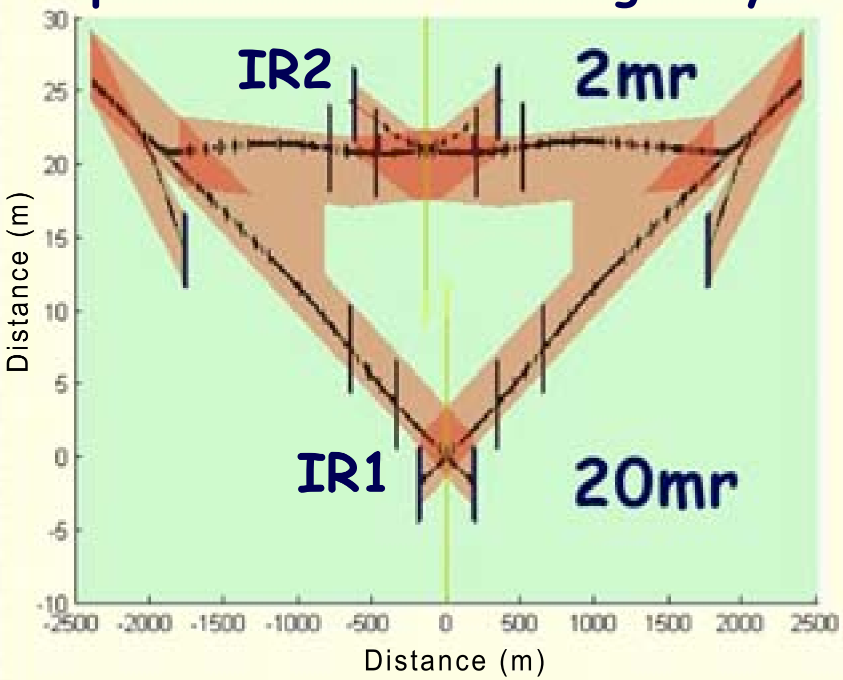
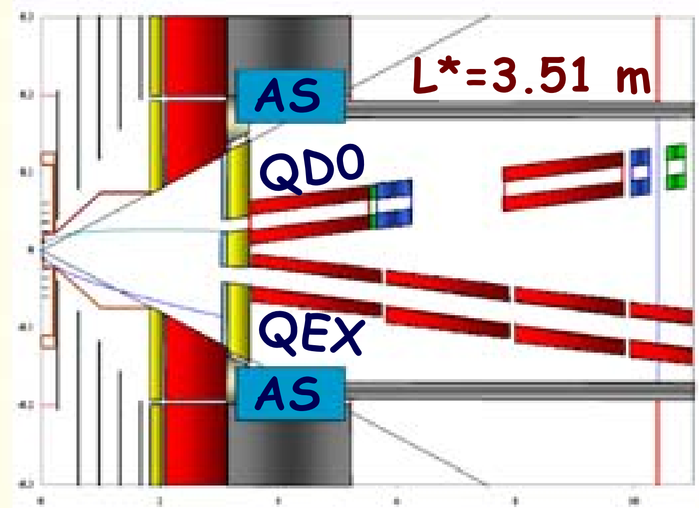
Proposed ILC Straw Design Layout



IR1 Layout Schematic (plan view)



Disrupted beam from IP goes outside QD0 into extraction line.

Extraction line magnets provide compensation for external field from incoming beam line magnets plus optical focusing needed for post IP diagnostics and spreading beam spot on the final beam absorber.

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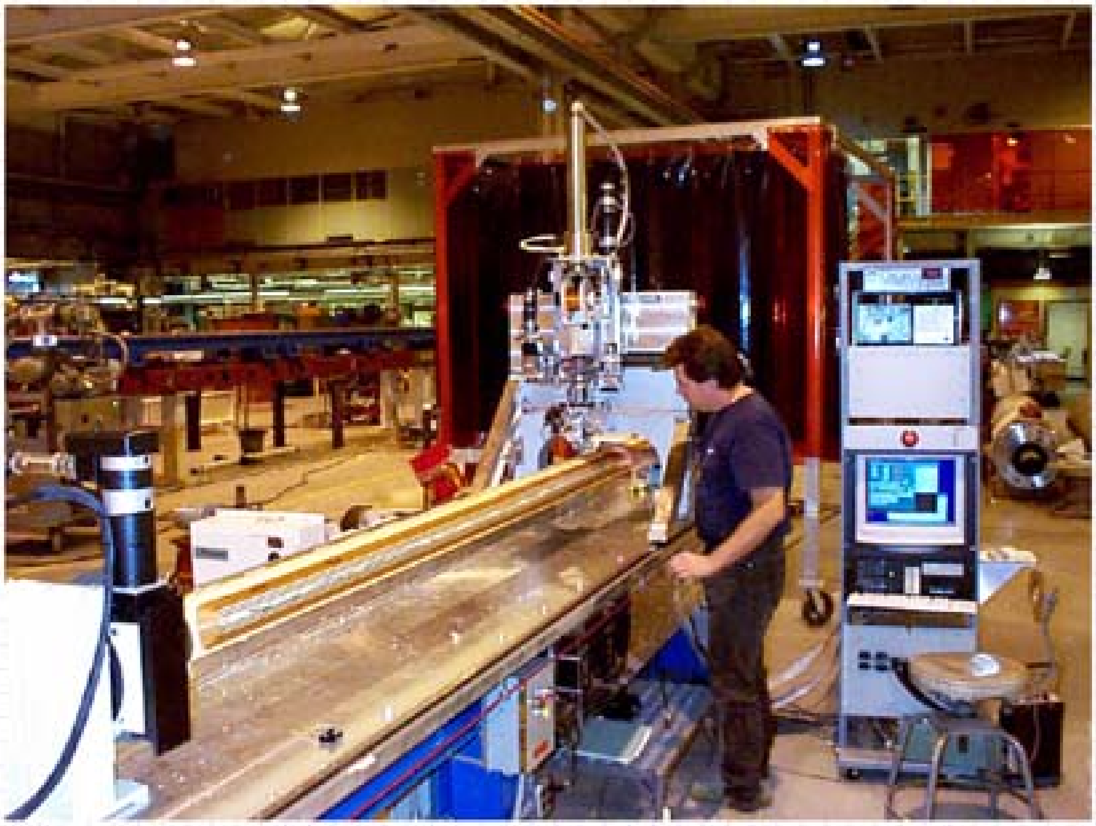
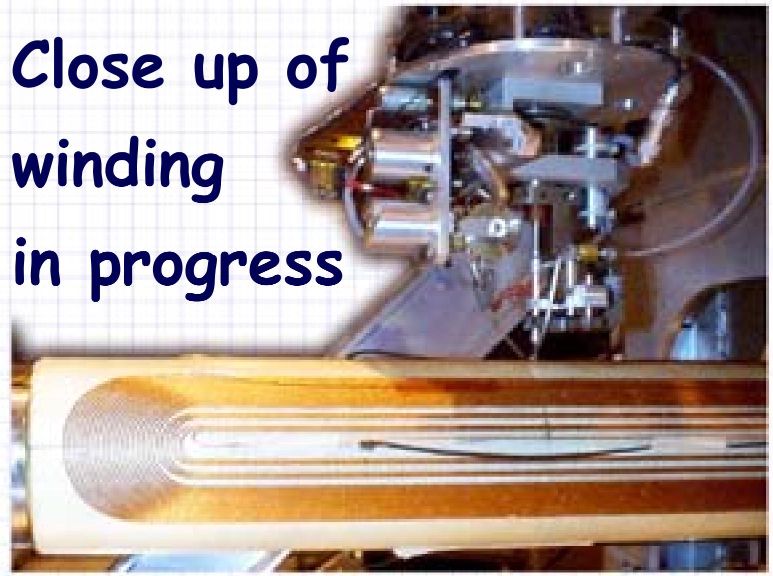
Take advantage of BNL experience making superconducting magnets for HERA-II.

...BNL Direct Wind Superconducting Magnets



Production of IR magnets for the HERA-II luminosity upgrade using a computer controlled winding machine.



Close up of winding in progress

Ultrasonic heating bonds epoxy coated conductor to substrate on a support tube (tack in place).

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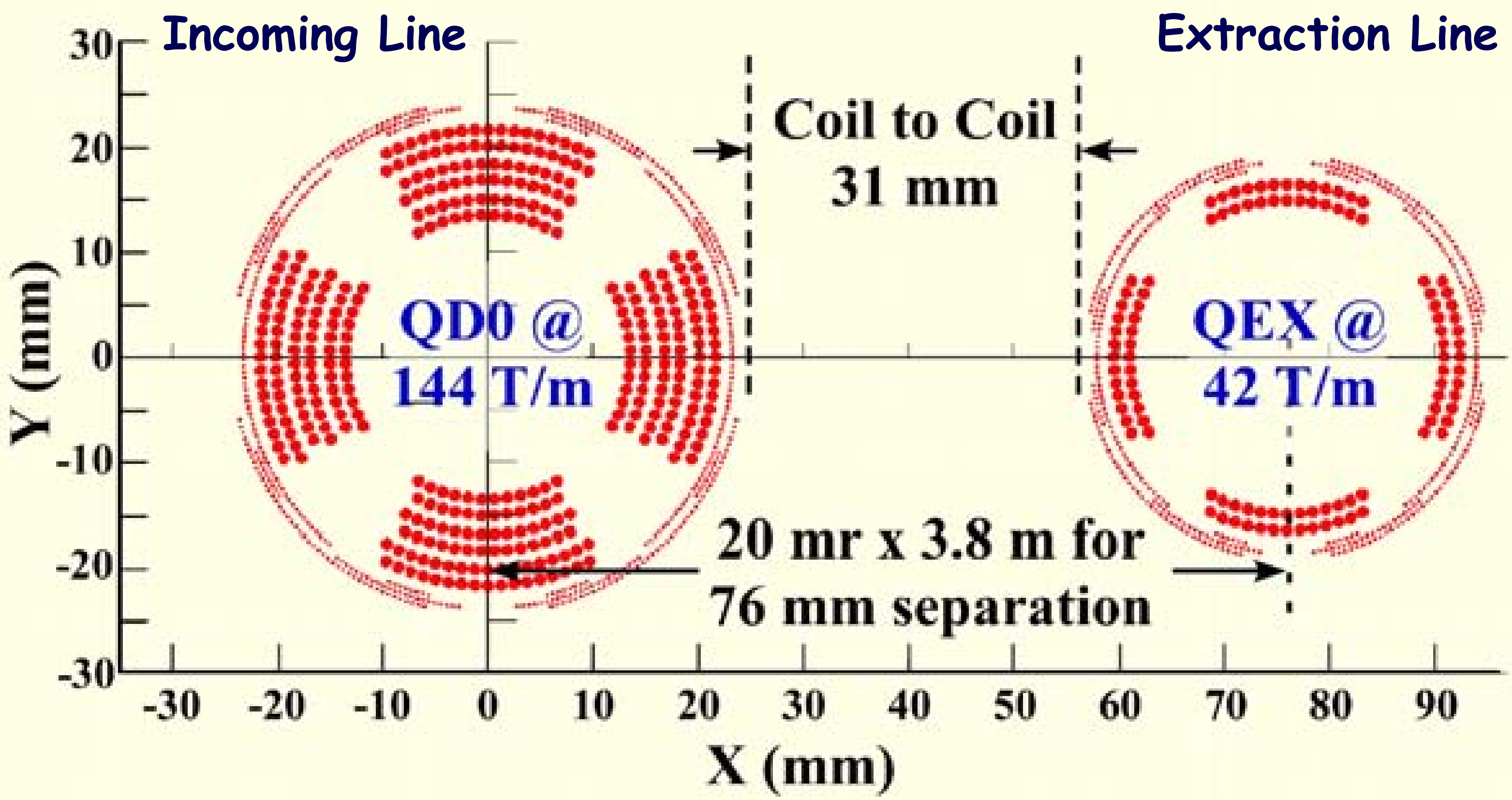
Side-by-side magnet configuration with correction elements made possible by direct wind production.



Side-by-side QD0 and QEX magnet coils (cross section at location 3.8 m from the IP).

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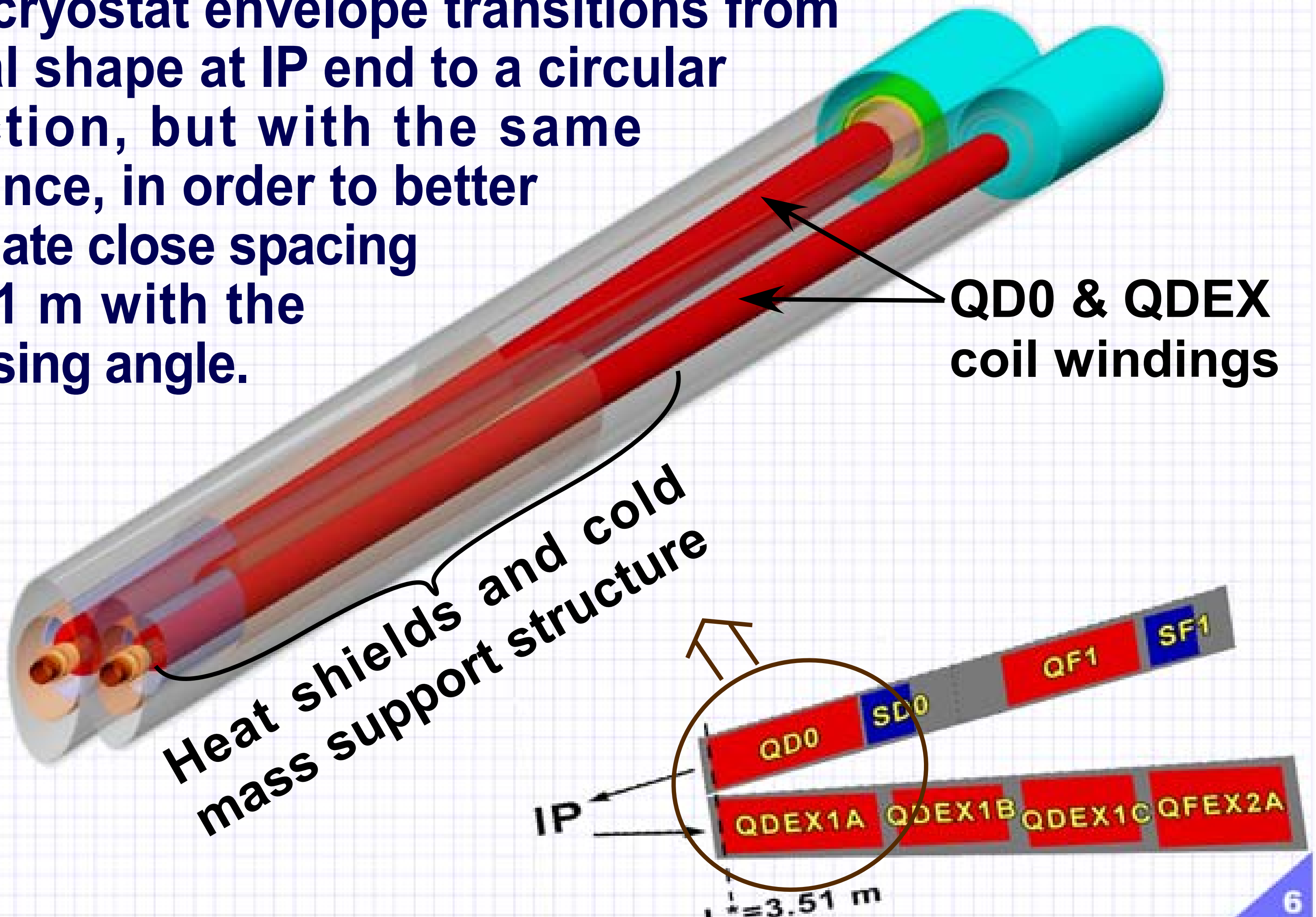
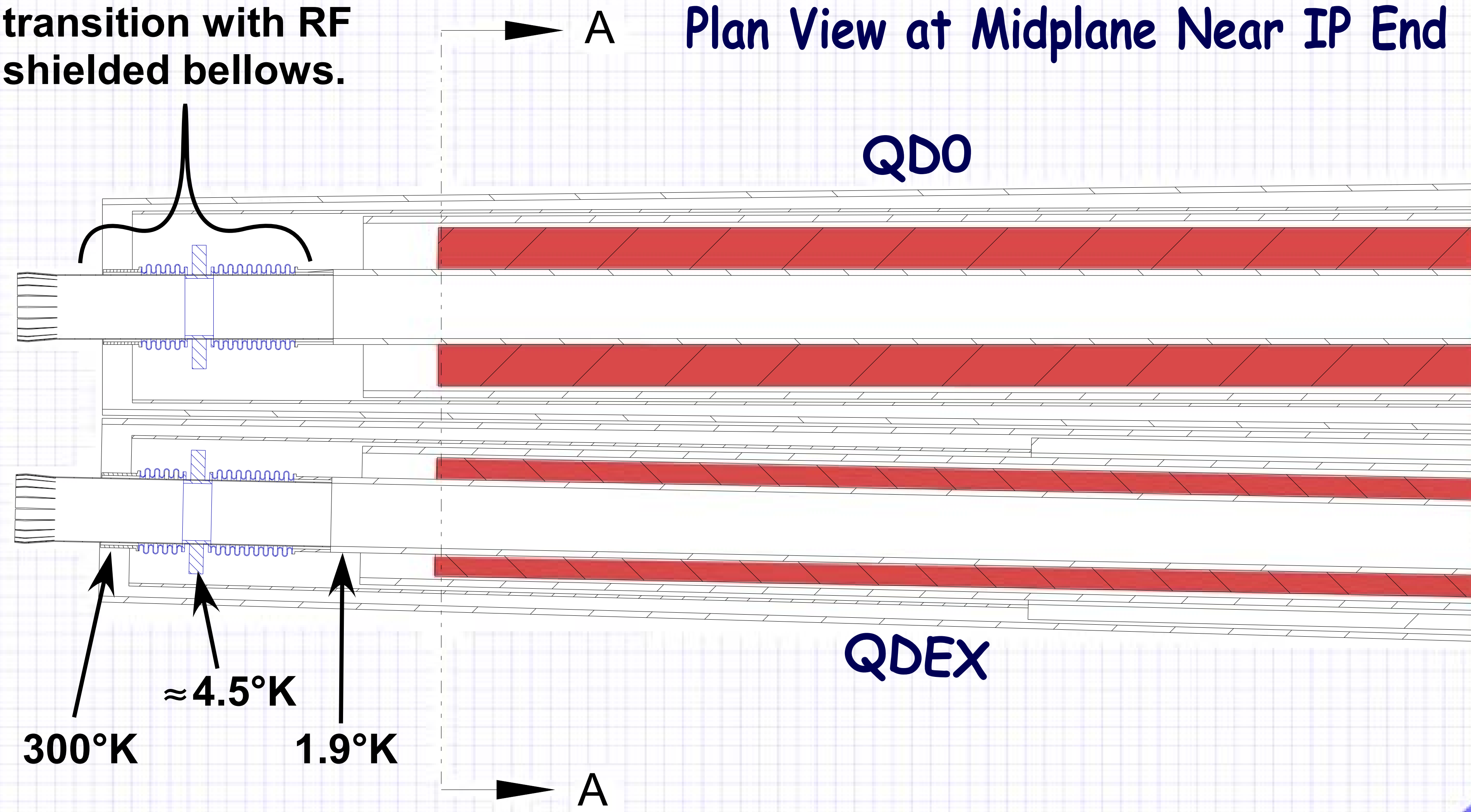
CAD Model: Look to have independent cryostats for incoming/extraction lines.

Note: The cryostat envelope transitions from an elliptical shape at IP end to a circular cross section, but with the same circumference, in order to better accommodate close spacing at L* = 3.51 m with the 20 mr crossing angle.



CAD Model: Horizontal section at the IP end (end transition region).

Budget for warm-to-cold transition with RF shielded bellows.



CAD Model: Section perpendicular to QD0 axis at IP end of coil windings.

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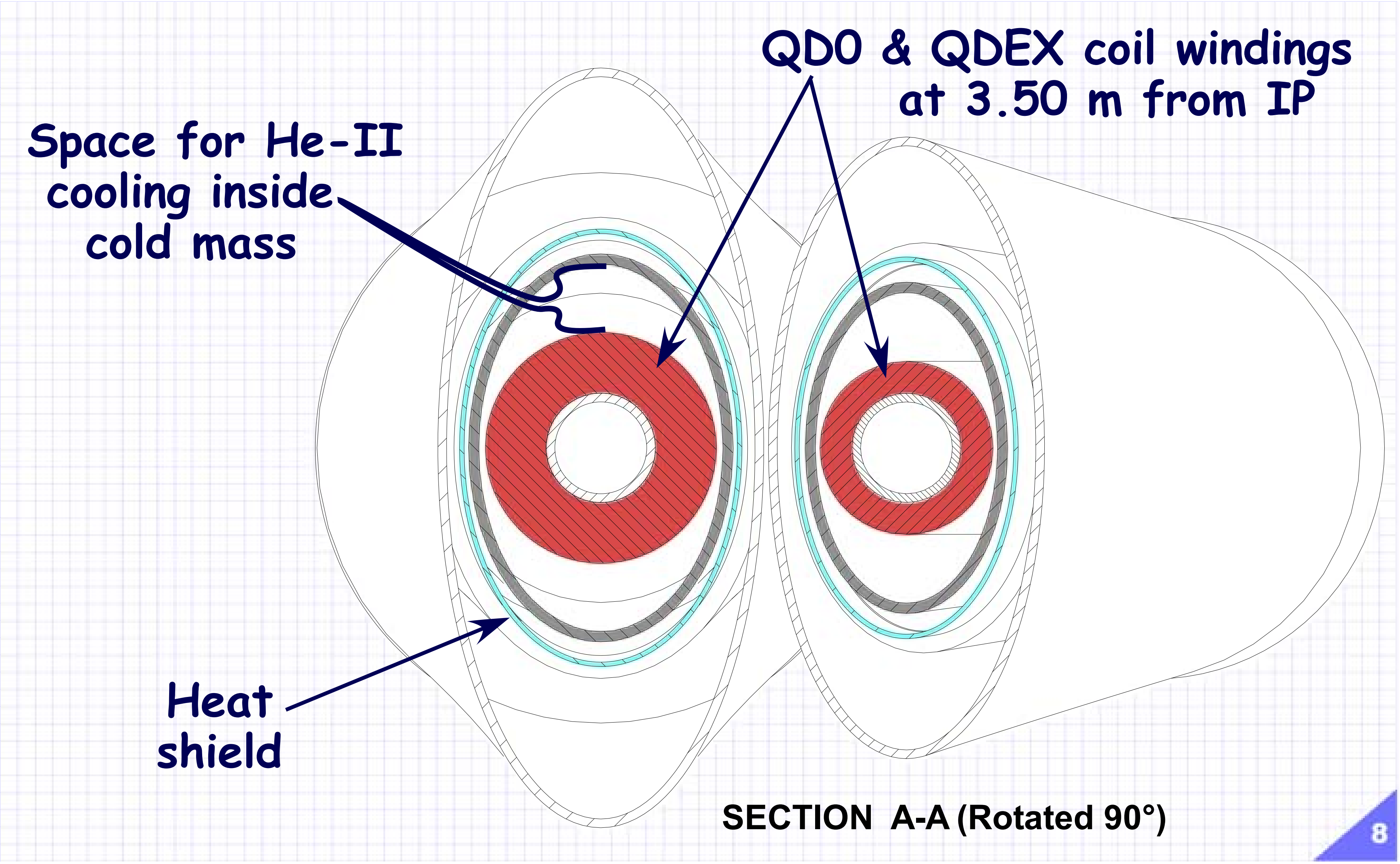

CAD Model: Expanded view at IP end showing QD0, QDEX and Anti-solenoid.

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Anti-solenoid coil shown along with inner and outer cryostat layers

Solid model view with end pieces removed for clarity

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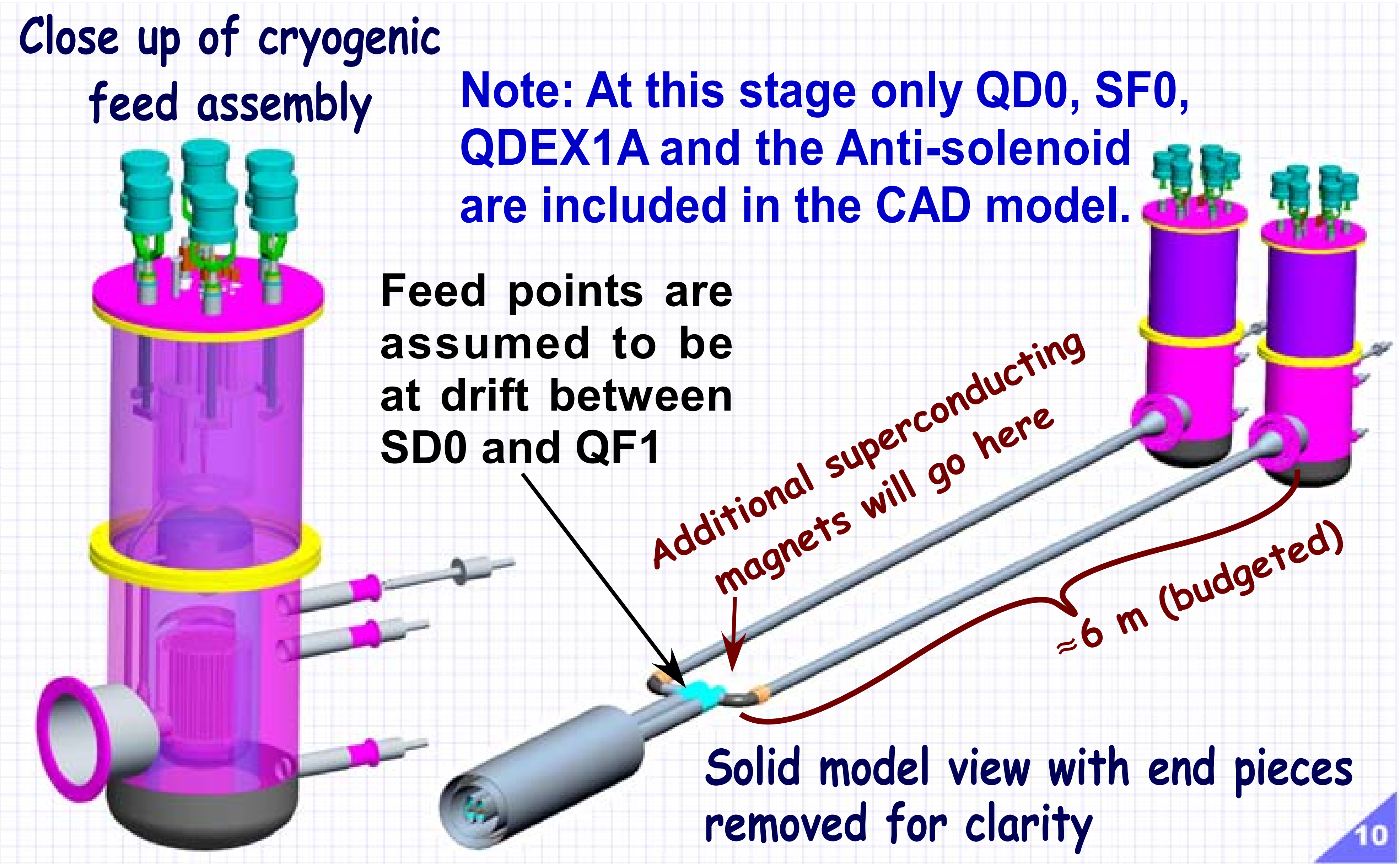
CAD Model: Full 3D view of model and expanded detail of cryogenic assembly.

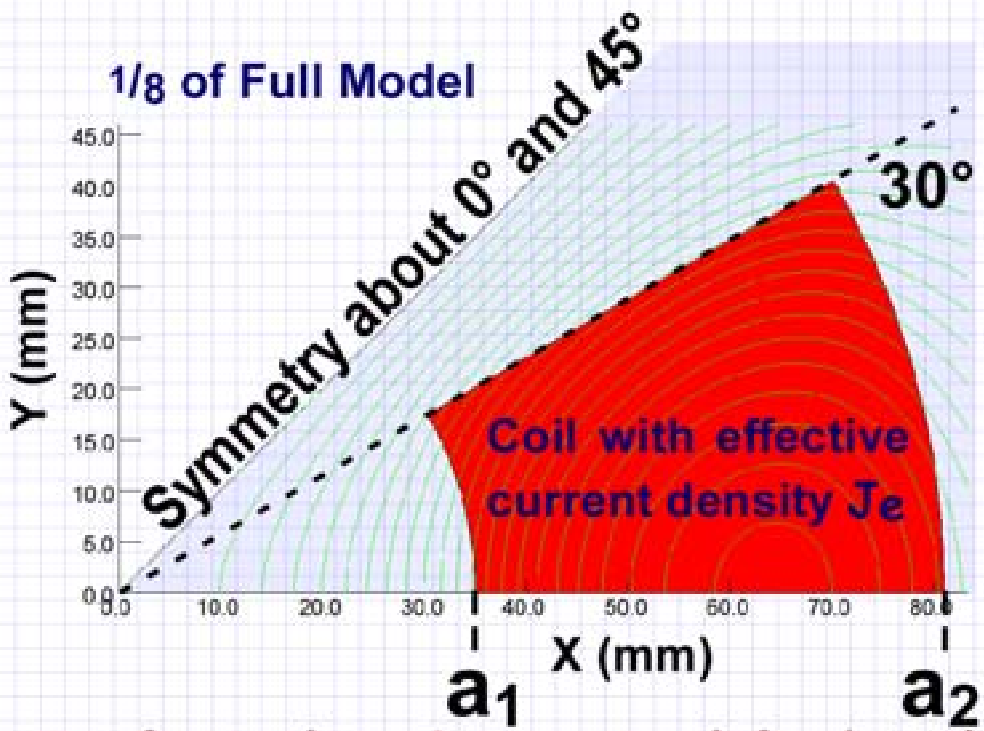


For quadrupole with no magnetic yoke, use simple formula to estimate transfer function.

For a cos(2θ) current distribution, $G = \sqrt{3}\, \mu_o\, J \ln(a_2/a_1) / \pi$

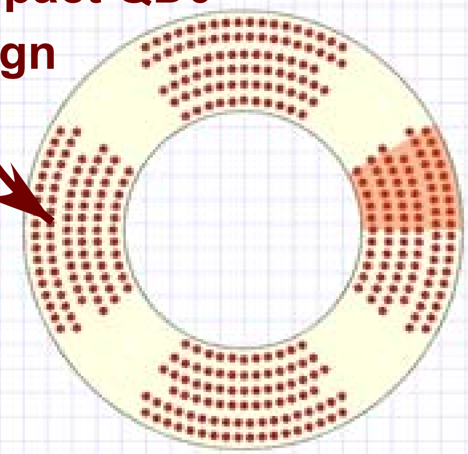
$= 0.693\ J \ln(a_2/a_1)$

(J in A/mm² for G T/m)



In fact the above simplified coil geometry approximates cos(2θ) fairly well.

Compact QD0 Design



$a_1 = 13.3$ mm

$a_2 = 21.4$ mm

$I_o = 711$ A

N/pole = 44

NI = 31.27 kA

Wedge Area = $\pi/12\ (21.4^2 - 13.3^2)$

$= 73.58\ \mathrm{mm}^2$

For $J_e = 425\ \mathrm{A/mm}^2$

Test: Get G = 140 T/m, the right answer.

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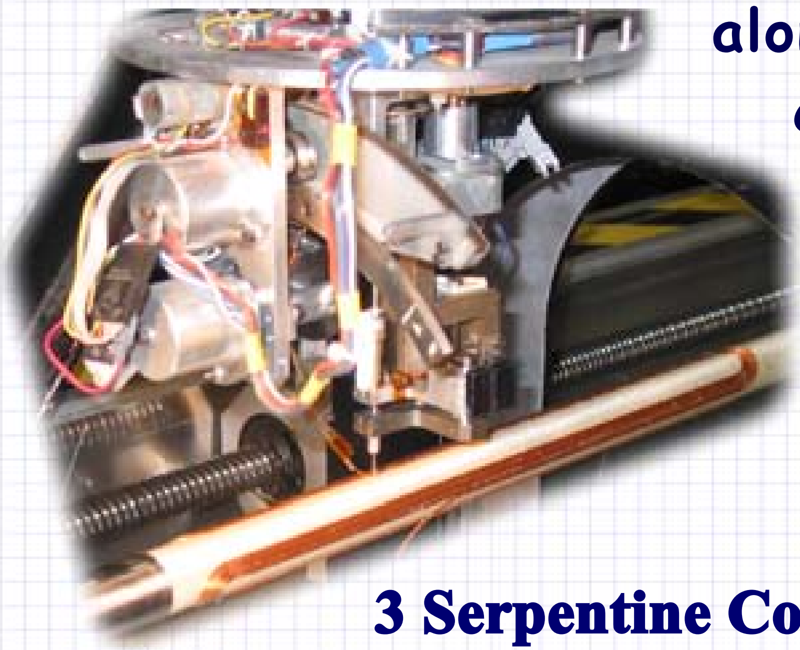
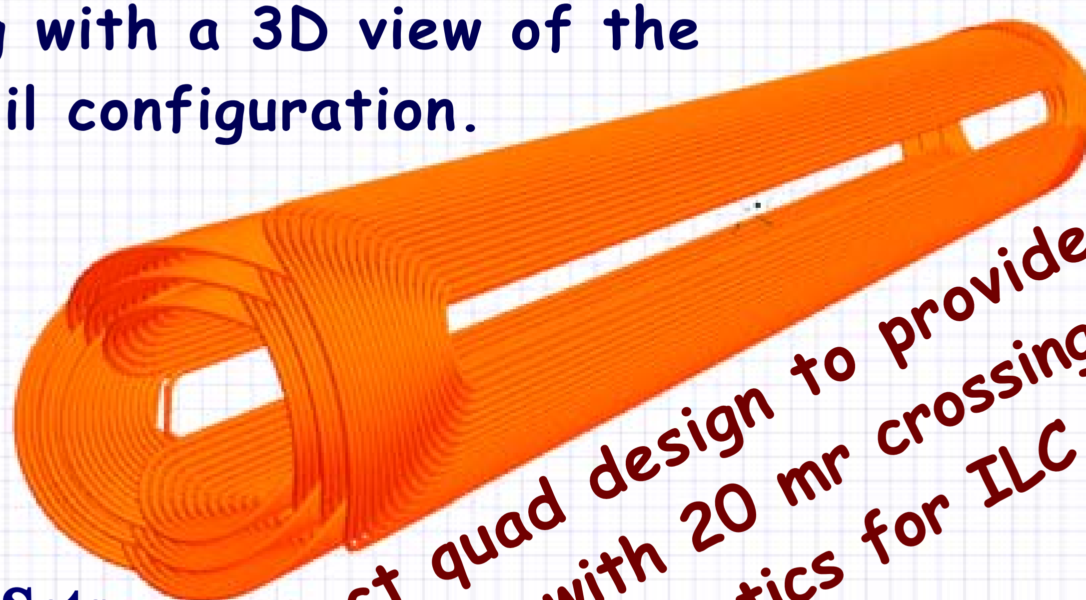
Compact Quadrupole Design for the ILC 20 mr Final Focus Layout: Prototype, QT.

Start of winding for ILC QD0 Prototype Test Magnet, QT, along with a 3D view of the coil configuration.





3 Serpentine Coil Sets
Giving 6 Cable Layers

Compact quad design to provide 140 T/m with 20 mr crossing angle optics for ILC.

Production of the QD0 Test Prototype (QT) is now complete along with warm field harmonic measurements. QT was cold tested in an existing BNL dewar at 4.2 to 3.0°K, 1 to 10 A/s ramp rate and solenoidal background fields up to 6 T.

Integral Field Quality Achieved with the QD0 Magnetic Prototype, QT.

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Integral Field Quality in the ILC QT Prototype
Warm Measurements After All Coil Sets Wound
Harmonics in "Units" at a Reference Radius = 5 mm

L_{coil} = 380 mm for 140 T/m
I_{op} = 664. A
Harmonics were corrected using final coil set C.

Harmonic Number	Coils A+B+C	
	Normal	Skew
T.F. (T/m/kA)	210.7	--
3	0.19	0.43
4	-0.03	1.49
5	-0.20	0.18
6	0.17	0.09
10	-0.26	0.01

Note: During production we learned to decrease turn spacing & bend radius for a net 7% TF gain.

Cold Test Setup for Quench Testing QT in an Existing Dewar and 8 T Solenoid.

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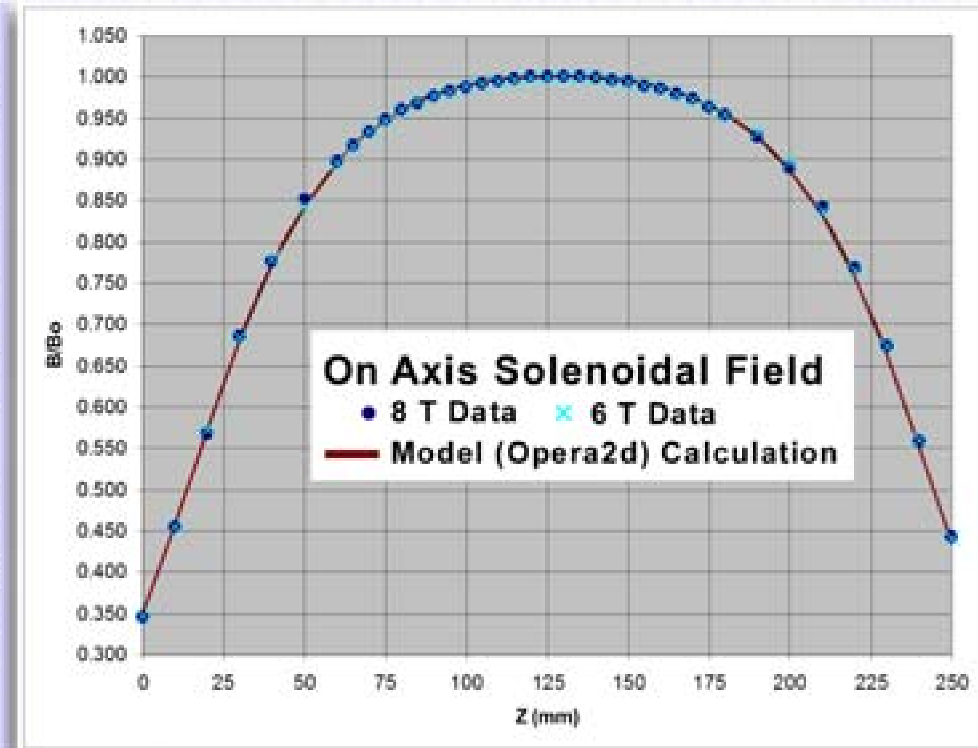
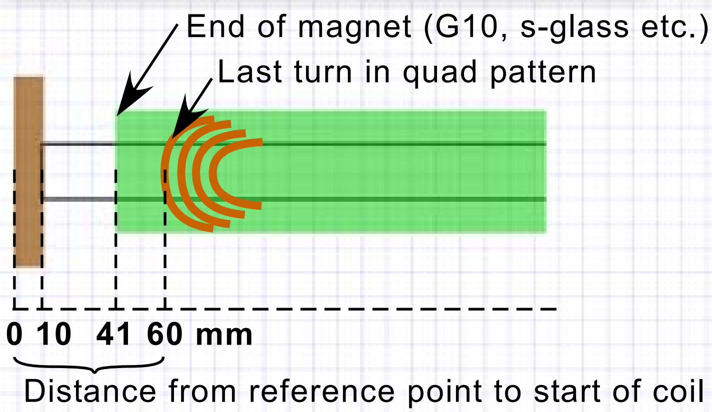
Cold (quench) testing was performed in an existing lab dewar with an 8 T solenoid. By reducing the helium pressure we tested QT at different background fields and temperatures in the range 0 - 6 T and 3.0 - 4.2°K.





The field distribution from the test solenoid was modeled and compared to measured (on-axis) data. The off-axis behavior (B_z, B_r) was calculated using the model to find the expected high field points in the QT coils.

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Summary of QT Cold Test Results.

- QT reached "short sample" with only two training quenches (both of which were above I_{op}).
- QT ran 13% above 140 T/m in 3 T background field at 4.3°K and almost reached operating gradient at 4 and 5 T background at 4.22°K.
- By pulling a vacuum on the test dewar, we brought QT to 3°K & got similar result @ 6 T background.
- At 2.5°K the LHe level fell below the end of the leads and we could not test at lower temperatures (simple pumping with no λ-plate).
- Still from these data we expect that at 1.9°K and 3 T background field I_q should be 1100 A (I_{op} = 664 A).

QT Quench Test Results

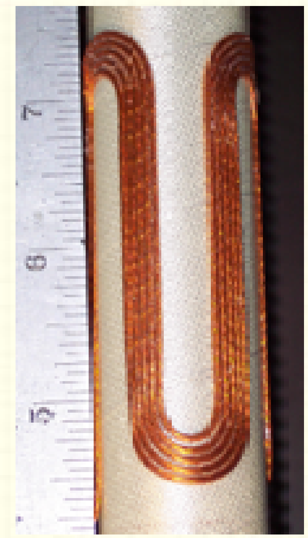
Background Solenoid (T)	Temp (°K)	Gradient (T/m)
3	4.30	158
4	4.22	139
5	4.22	134
6	3.00	137

Note: Operational Target is 140 T/m with 3 T solenoidal background field while cooled with pressurized He-II @ 1.9°K. Above data scale to 232 T/m under these conditions (for 60% short sample current).

Increased background field permits reaching large Lorentz forces but without having to go to excessive test currents.

Summary: Compact Superconducting Magnet Solution for 20 mr Crossing Angle Final Focus

We are developing compact superconducting cryostat & cryogenic supply concepts (work for MDI); and made & tested a prototype with excellent field quality & quench performance (even with background field). Next we may make a very short sextupole using the same seven-strand cable to extend technology to tighter bends (maybe for small-aperture "CLIC-like" quads) and lower dewar test temperatures (could reach 1.8°K if magnet was shorter).



Small Aperture ILC Sextupole

Ultimately we want to construct full length coils which should be fully cryostated and horizontally tested in order to develop better understanding of the final doublet vibration/mechanical stability challenges that are yet to be fully addressed.