# BNL Direct Wind Magnets*

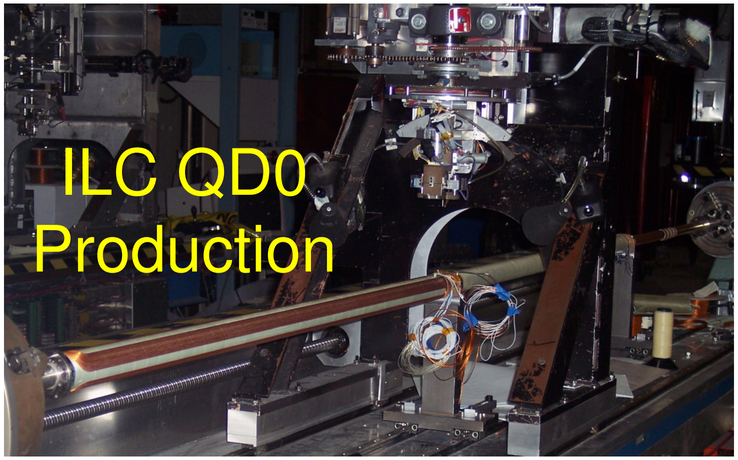
presented by Brett Parker, BNL-SMD

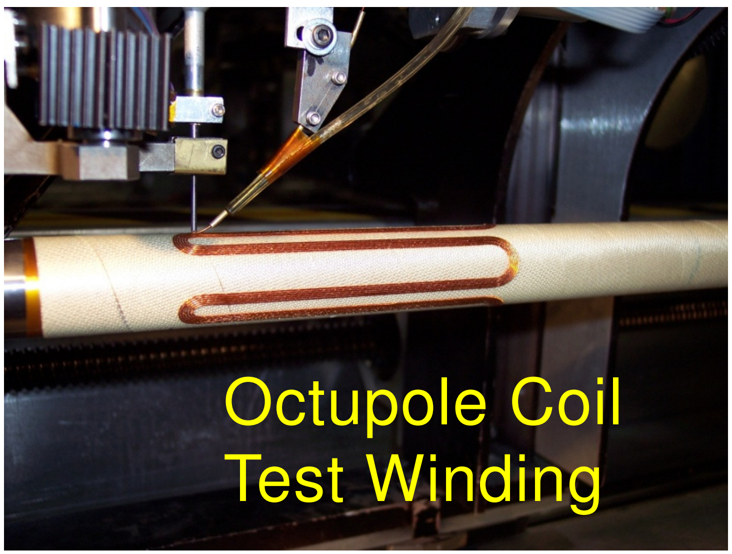
*In memory of Pat Thompson

# Outline: BNL Direct Wind Magnets

- Overview production process and terminology.
  - **Coil Winding, Wrapping, Measurement, and Curing**
  - **Planar Patterns versus Serpentine Coils**
  - **Multifunction, Multi-Layer Coils and Field Quality**
- Examples from past and current projects.
  - **ILC QD0 R&D Prototype and ATF2 Upgrade Magnets**
  - **Experience from Alpha (anti-hydrogen trap), HERA-II and BEPC-II IR Magnets, and JPARC Correctors**
  - **eRHIC Final Focus Septum Magnet**

# 10 Basic Steps for Winding BNL Coils

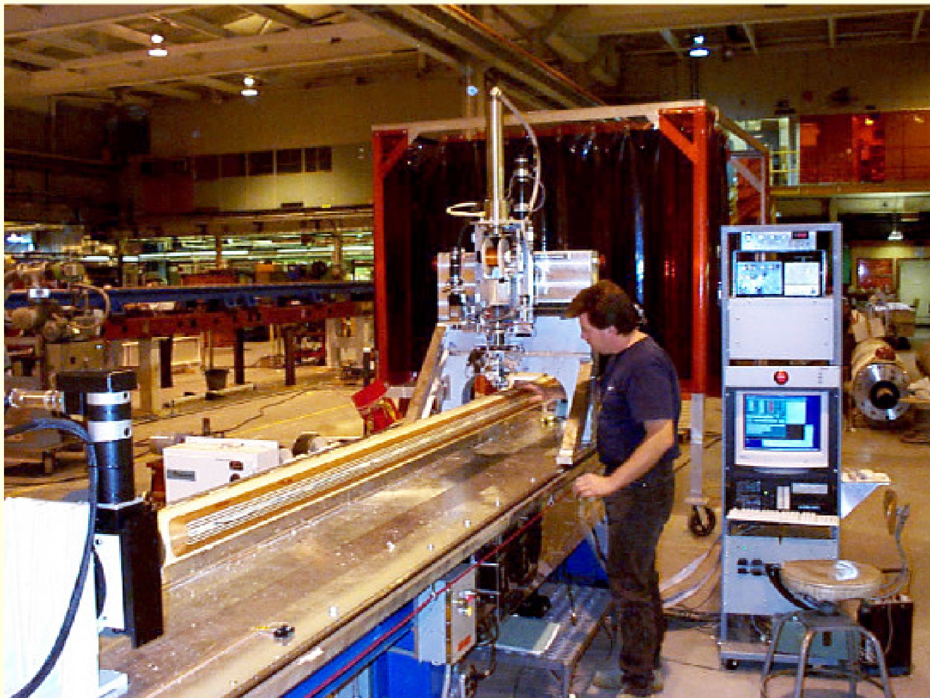


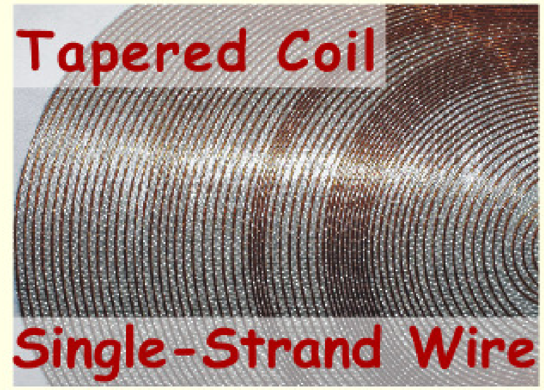

1. Support tube is wrapped with epoxy substrate.
2. Insulated conductor with epoxy coating pays out under stylus (7-strand cable or single strand).
3. Ultrasonic heating tacks conductor temporarily in place (i.e. rapid cooling after stylus moves on).
4. Coordinated motion: tube rotation, linear speed, angle-of-attack, stylus pressure, power etc.
5. Fill gaps in pattern with G-10 (or Nomex) & wet epoxy layup; if another layer go to step 1 (or 8).
6. Then tension wrap with fiberglass for pre-stress.
7. Do a high temperature cure of the coil structure.
8. Occasionally we will machine coil on a lathe to ensure that the outer coil surface is "round."
9. For best field quality, measure harmonic content of coil layers wound so far and prepare to make "corrections" to harmonics in later layers.
10. As needed go back to step 1.

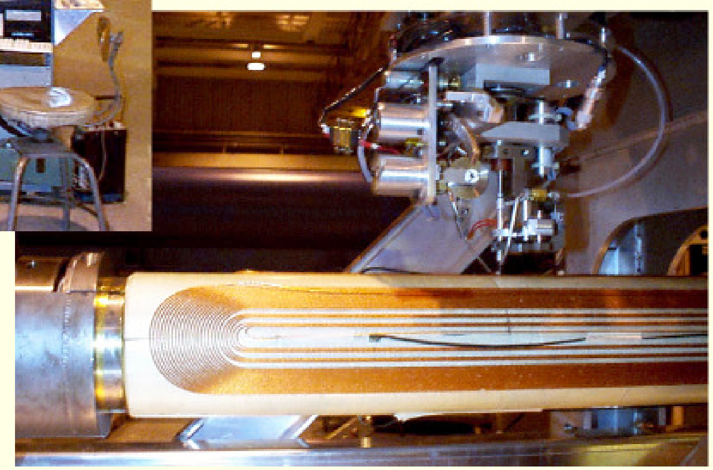
# HERA-II Production Overview

BNL Direct Wind,
The Early Days…



GG Harmonic Tuning



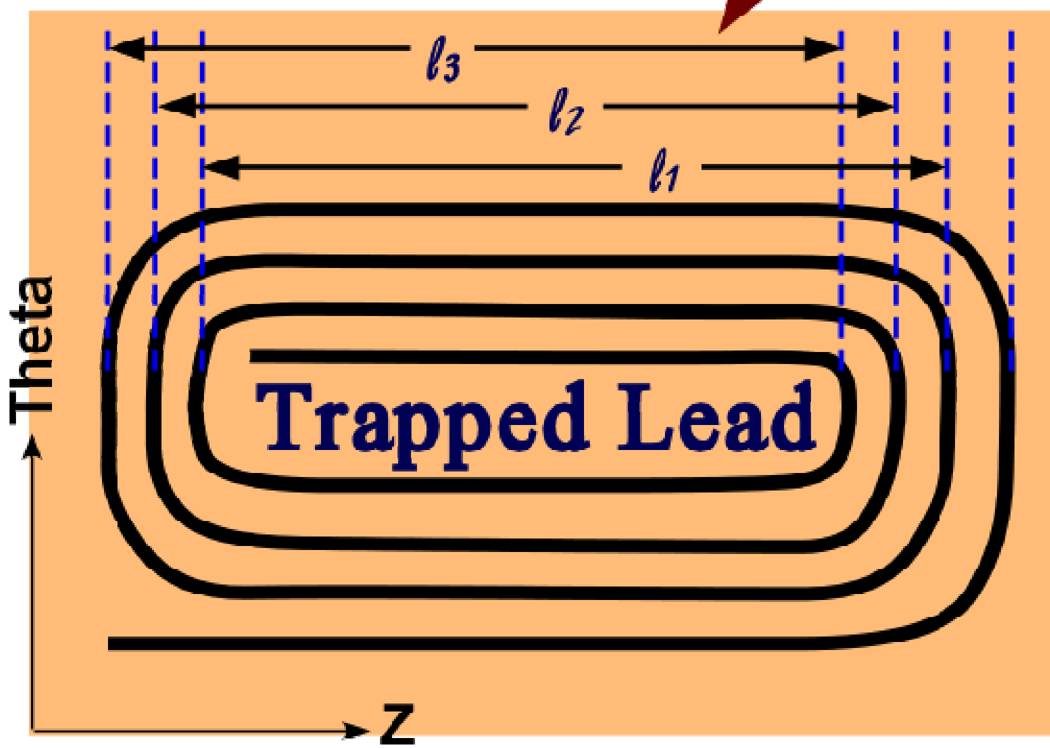
BNL computer controlled winding of two types of multi-coil magnets for the HERA-II upgrade.

GO Quadrupole (cable)

# "Planar patterns" impact direct wind coil production in multiple ways

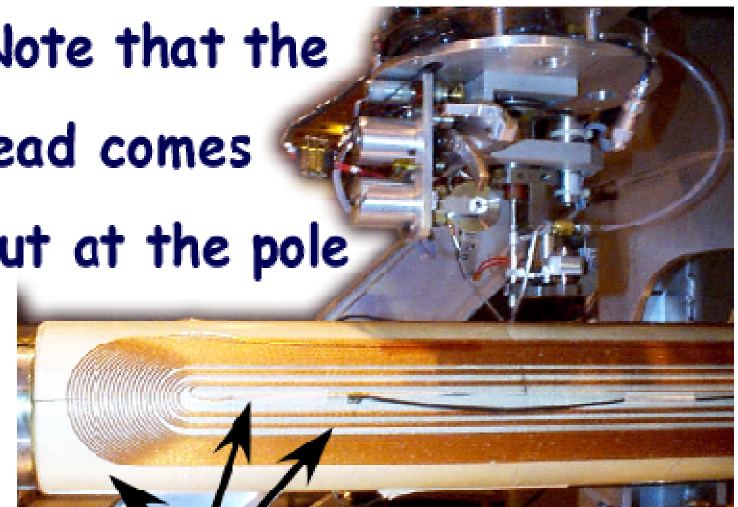
## ... Coil Topology ....

Turn length is correlated with angle.




Though winding goes directly on tube, we still used RHIC corrector style patterns, now called planar patterns.

Note that the lead comes out at the pole

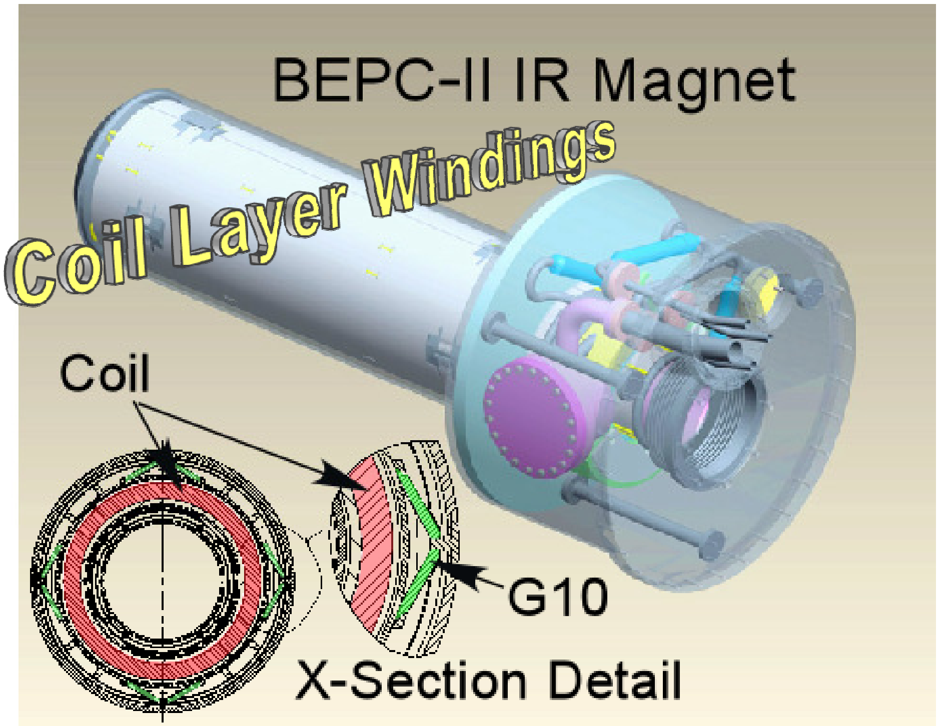


After winding next step is filling gaps at poles and harmonic tuning spacers with G10 & epoxy before wrapping with tensioned fiberglass to provide coil prestress.

# The BEPC-II IR Magnet Design

| Name | Function | Layers | Conductor |
|---|---|---|---|
| SCQ | Main Quad | 8 | 7 strand cable |
| SCB (HDC) | Hor. Dipole | 2 | 7 strand cable |
| VDC | Vert. Dipole | 2 | 1 strand wire |
| SKQ | Skew Quad | 2 | 1 strand wire |
| AS1 | Anti-Solenoid | 6 | MRI wire |
| AS2 | Anti-Solenoid | 2 | MRI wire |
| AS2 | Anti-Solenoid | 6 | MRI wire |

**28 Different Coil Layer Windings**

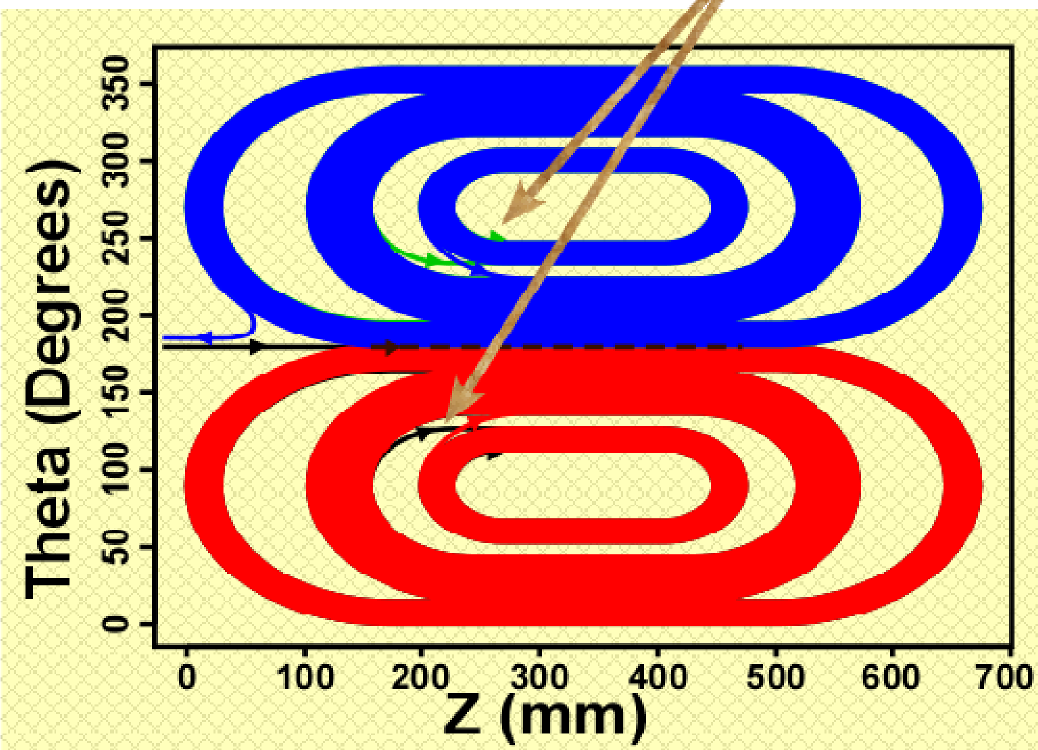



*Compared to HERA-II magnets, these have almost double the aperture but only 1/7 the length. The radial budget does give more space for the cryostat (...that is used to provide a warm bore tube, inner and outer heat shields and LHe cooling flow on both sides of a thicker coil pack).*

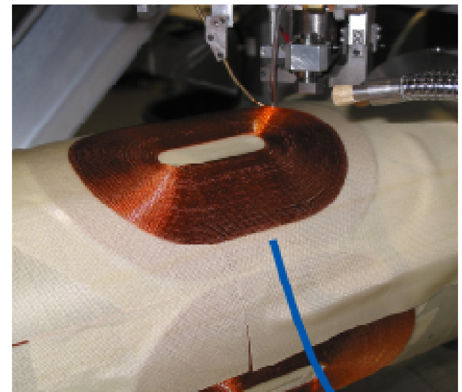
# Initial BEPC-II: Look to go out of plane and wind dual-layer planar patterns.

## ... Coil Topology ....

Black & Green layers below Red & Blue.

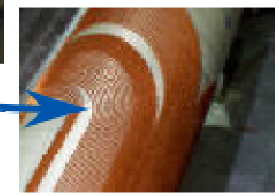



Dual-layer Coils: Spiral in to the pole; jump up & spiral out; jump down & spiral in; finally jump up and spiral out.



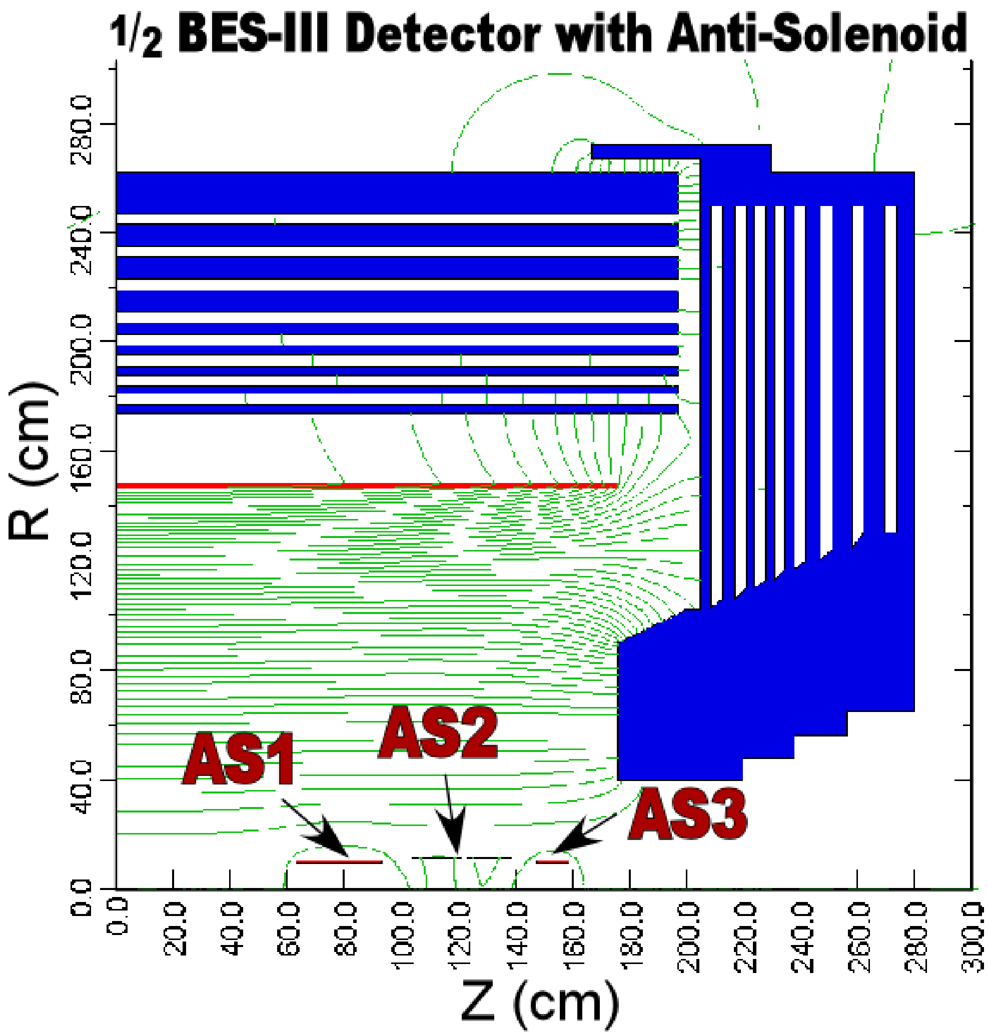
Two layers wound one on top the other

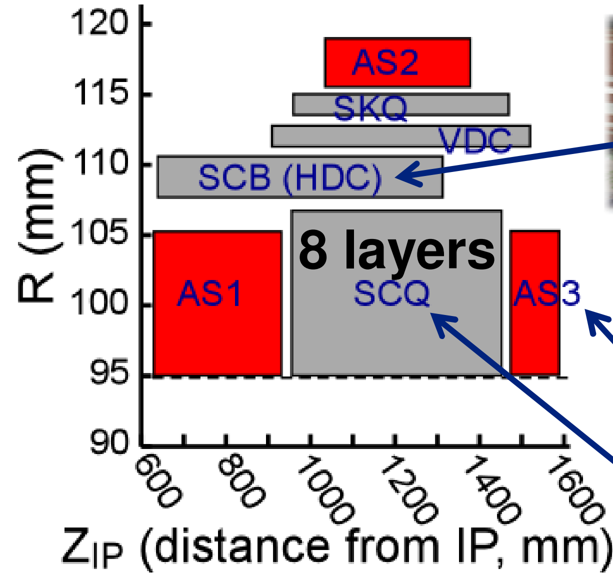
We finally want something like this



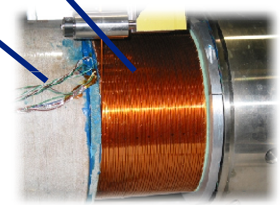
BEPC-II quad design has 8 cable layers. Too many leads to do same as HERA-II (bend sharply & out over top of the final coil pack).

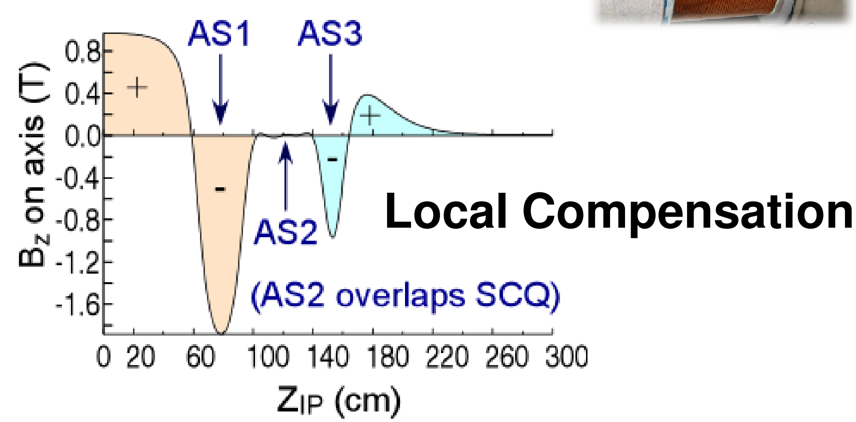
# BEPC-II Special Feature: Local BES-III Detector Solenoid Compensation Scheme



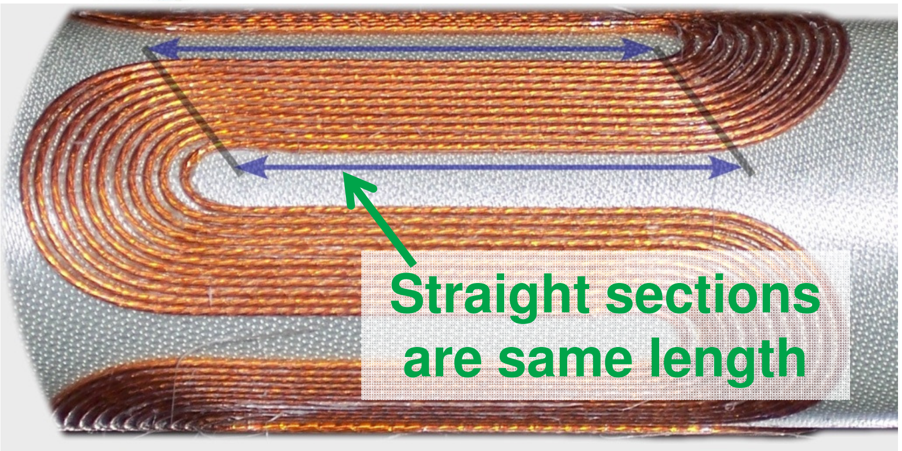






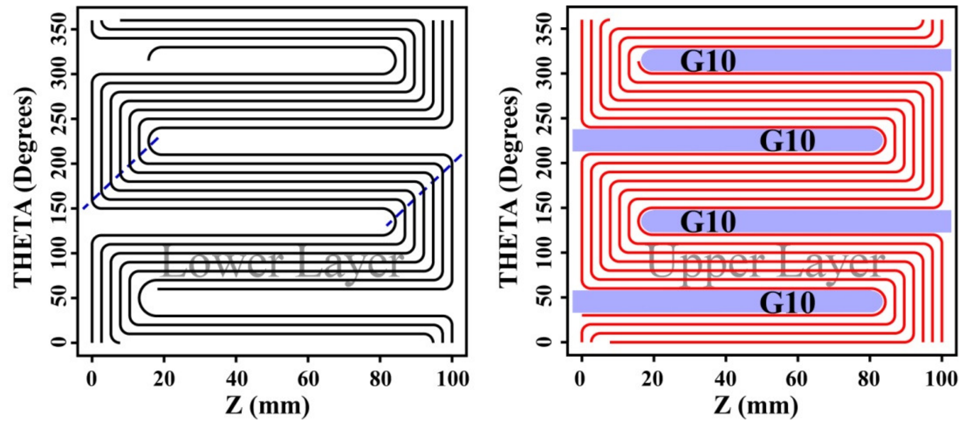
# BEPC-II Quadrupole (SCQ) Winding

# Some Coil Topology Considerations




## α Octupole Test Pattern

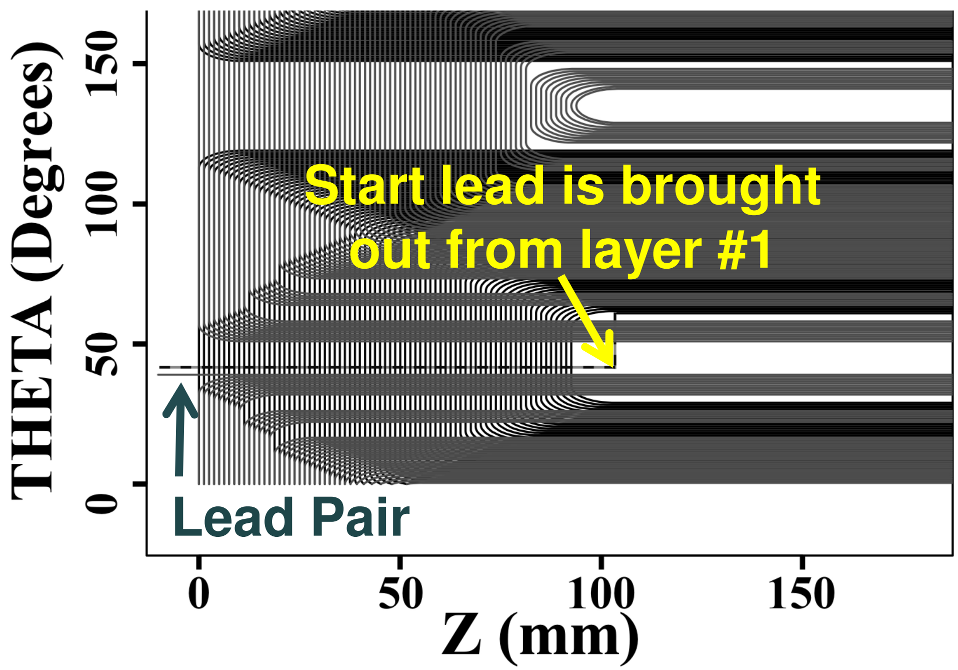
## Serpentine Style Coil Set

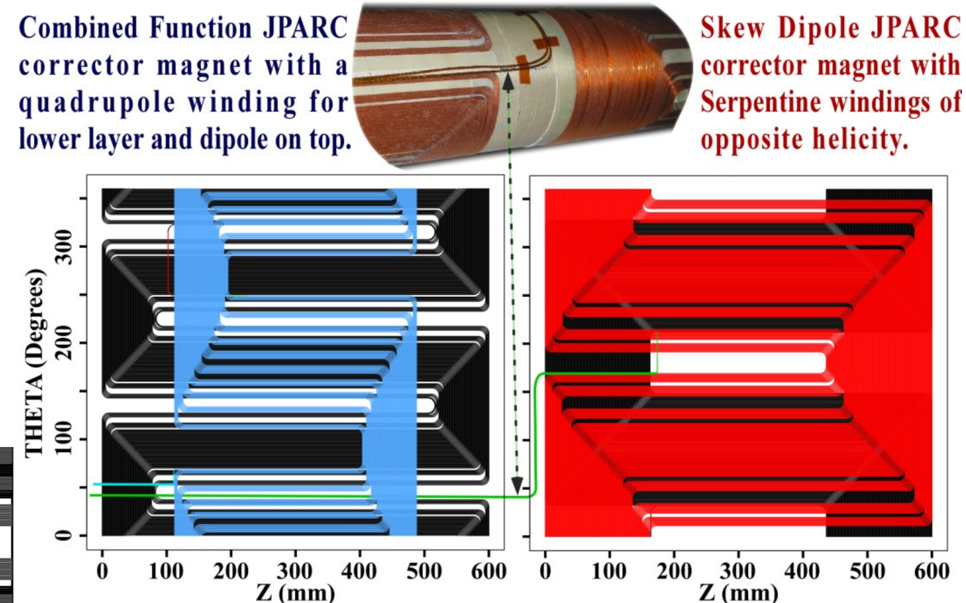



With Serpentine coil patterns we are able to continuously wind an entire coil layer at once. Integral and body (2D) harmonics match well but in order to avoid generating solenoidal field, we tend to wind them in alternate handed pairs, denoted "coil sets." Serpentine ends are very simple (no extra spacers) and tend to produce lower peak fields.

# Some Coil Topology Considerations

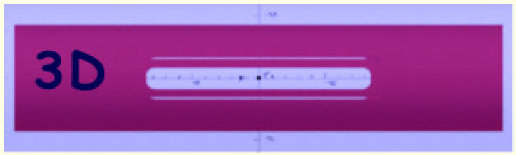
- With Serpentine patterns we are able to bring lead pairs out without using any extra radial space

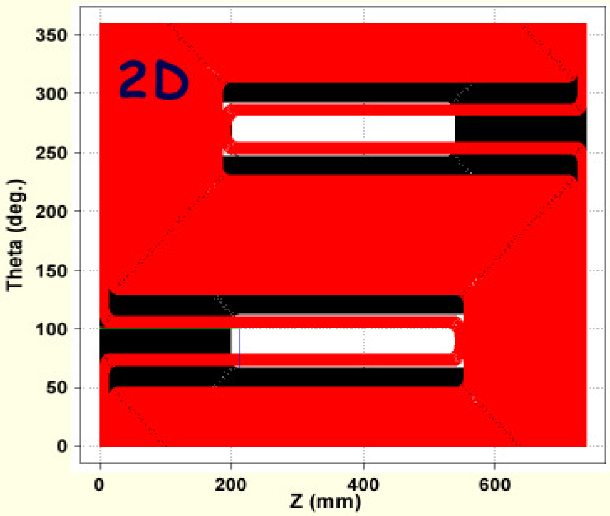


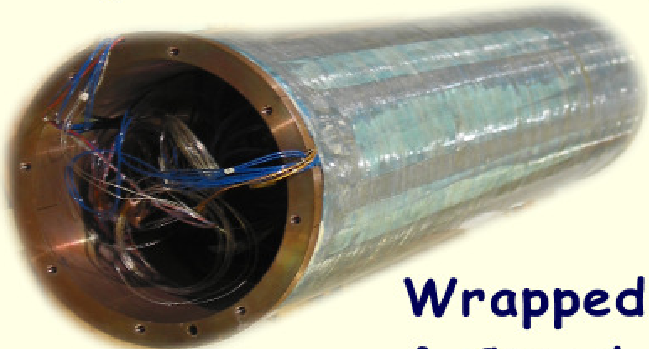

- A JPARC coil option had skew-quad leads brought past the dipole and quad correction windings to fit inside main dipole coil.

# JPARC Corrector Design Summary



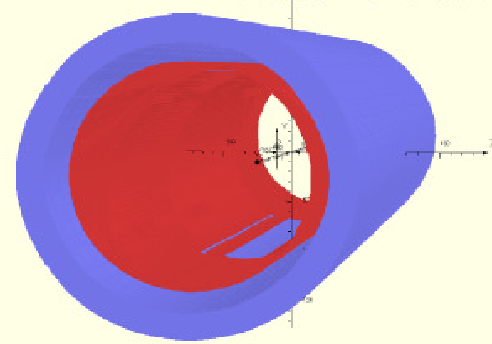



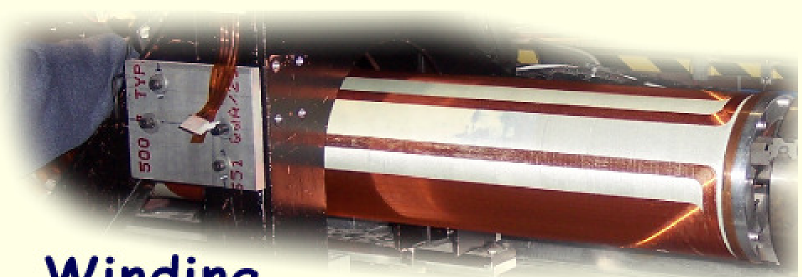

## Final: Conduction Cooled Dipole in a Magnetic Yoke



Wrapped & Cured

Coil+Yoke

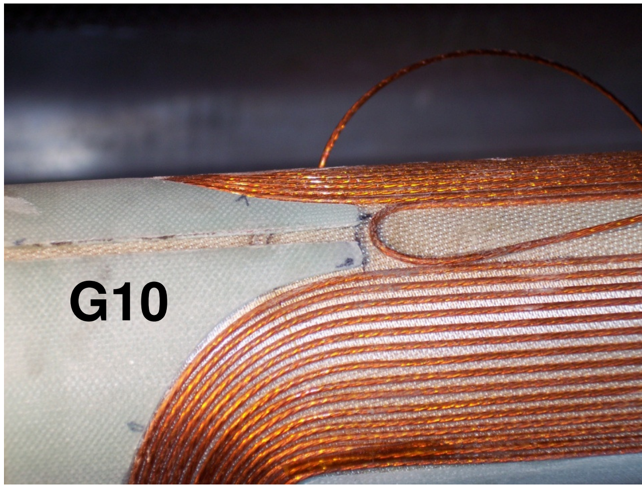




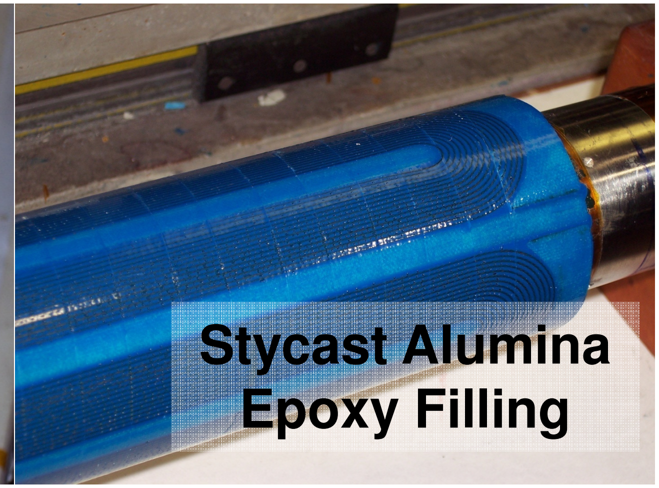
Winding

We can make a wide variety of interesting magnets, with and without yokes, by direct winding Serpentine style coil patterns.

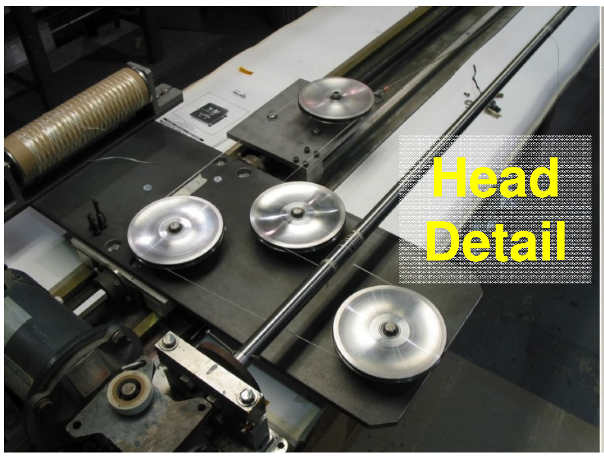
# Real coils: fillers, s-glass wrap, power leads, volt taps and sometimes heaters.

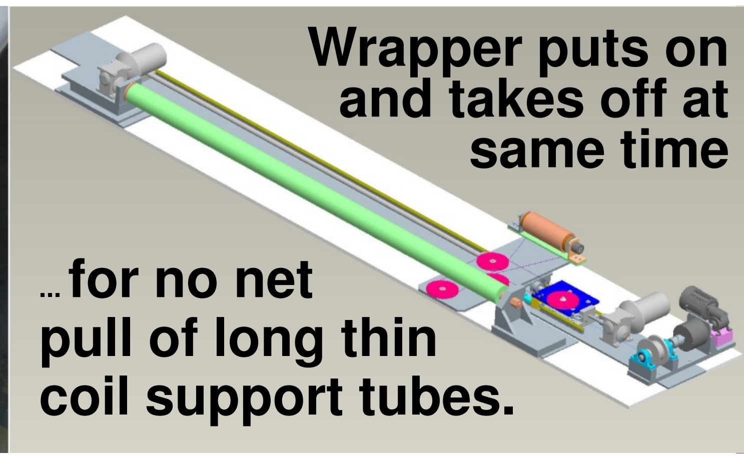


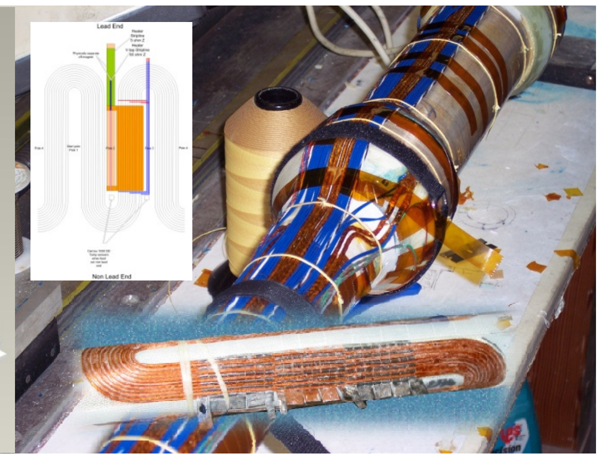





*G10 Fill Pieces* | *Current Leads & Voltage Taps* | *Epoxy Fill*

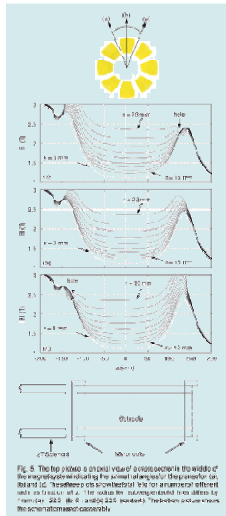


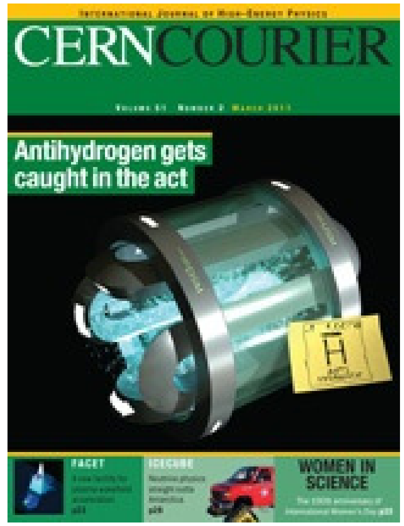



*The means to put s-glass prestress wrap on long thin tubes.* | *And More!*

# Alpha Antihydrogen Trap



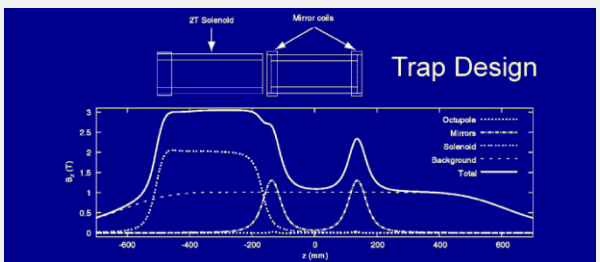



Fig. 6. Magnetic field on axis for the magnet assembly including the 1T background field from the large-diameter external solenoid (see Section 2.5).

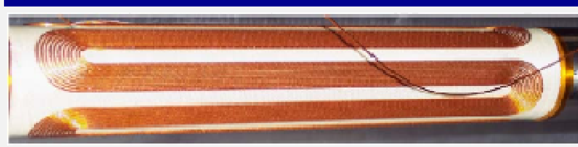


Fig. 7. First layer of the octupole. The wires are held in place by ultrasonic bonding; the spacers B-stage epoxy, and fiber overwraps have not yet been applied.

**Everyone sees the α magnet differently**

CERN Courier July/August 2011

News

CERNCOURIER

ANTIMATTER

## ALPHA traps antihydrogen for minutes

In November of 2010, the ALPHA collaboration at CERN's Antiproton Decelerator (AD) grabbed the world's headlines by trapping a handful of atoms of antihydrogen (*CERN Courier* January/February 2011 p7). The result demonstrated that it was, indeed, possible to produce trappable antihydrogen atoms. Now, the ALPHA team has shown that it can hold on to the trapped antiatoms for up to 1000 seconds and has succeeded in measuring the energy distribution of the trapped antihydrogen (ALPHA collaboration 2011).

Antihydrogen has been produced at CERN since 2002 by allowing antiprotons from the AD to mix with positrons in a Penning trap comprised of a strong solenoid magnet and a set of hollow, cylindrical electrodes for manipulating the particles. However, being neutral, the antiatoms are not confined by the fields of the Penning trap and annihilate in the apparatus. It has taken eight years to learn how to trap the antihydrogen, mainly because of the weakness of the magnetic dipole interaction that holds the antiatoms. The antihydrogen must be produced with a kinetic energy, in temperature units, of less than 0.5 K, otherwise it will escape ALPHA's "magnetic bottle". By contrast, the plasma of antiprotons used to synthesize the antihydrogen begins its time in ALPHA with an energy of up to 4 keV (about 50 million K).

The ALPHA antiatom trap consists of a transverse octupole magnet and two short solenoid or "mirror" coils – all fabricated at the Brookhaven National Laboratory (figure 1). This configuration produces a magnetic minimum at the centre of the device (*CERN Courier* March 2011 p13). Antihydrogen forms at the magnetic minimum and cannot escape if its energy is below 0.5 K. To see if there is any antihydrogen in the trap, the team rapidly shuts down the magnets (9 ms time constant). Any escaping antiatoms are revealed by their annihilation, which is registered in a three-layer, silicon vertex detector. In 2010, antiatoms were trapped for 172 ms, the minimum time necessary to make certain that no bare antiprotons remained in the trap, and the experiment detected 38 events consistent with the release of trapped antihydrogen.

The ALPHA team has subsequently worked to improve the trapping techniques, succeeding in particular in increasing by a factor of five the number of antiatoms trapped in each attempt; the total number trapped has now risen to 309. The improvements include the addition of evaporative antiproton cooling and optimization of the autoresonant mixing that helps to produce the coldest-possible antiatoms. The team then made measurements in which they increased the time in the trap from 0.4 to 2000 s, yielding 112 detected annihilations in 201 attempts (figure 2). The probability that the detected events are background from cosmic rays is less than $10^{-15}$ ($8\sigma$) at 100s, and $4\times10^{-3}$ ($2.6\sigma$) at 2000s. Calculations indicate that most of these trapped antiatoms reach the ground state – which is crucial for future studies with laser and microwave spectroscopy.

The distributions in space and time of the annihilations of the escaping antiatoms are already providing information about their energy distribution in the trap. This can be compared with a theoretical model of how the team thinks the antihydrogen is being produced in the first place.

The long storage time implies that the team can begin almost immediately to look for resonant interactions with antihydrogen – even if only one or two atoms occupy the trap at any given time. For example, resonant microwaves will flip the spin of the positron in the trap, causing a trapped atom to become untrapped, and annihilate. The ALPHA collaboration hopes to begin studies with microwaves in 2011, aiming for the first resonant interaction of an antiatom with electromagnetic radiation. In the longer term, the ALPHA2 device will allow laser interaction with the trapped antiatoms in 2012 – the first step in what the team hopes will be a steady stream of laser experiments with ever-increasing precision.

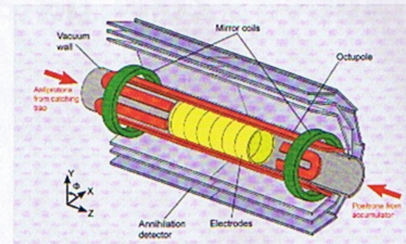


*Fig. 1. Diagram of the ALPHA central apparatus showing the Penning trap electrodes, magnets for the atom trap and the silicon vertex detector.*

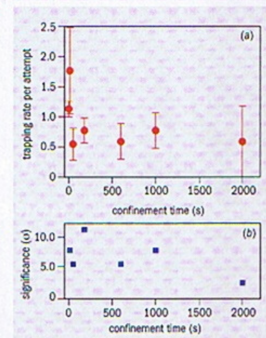


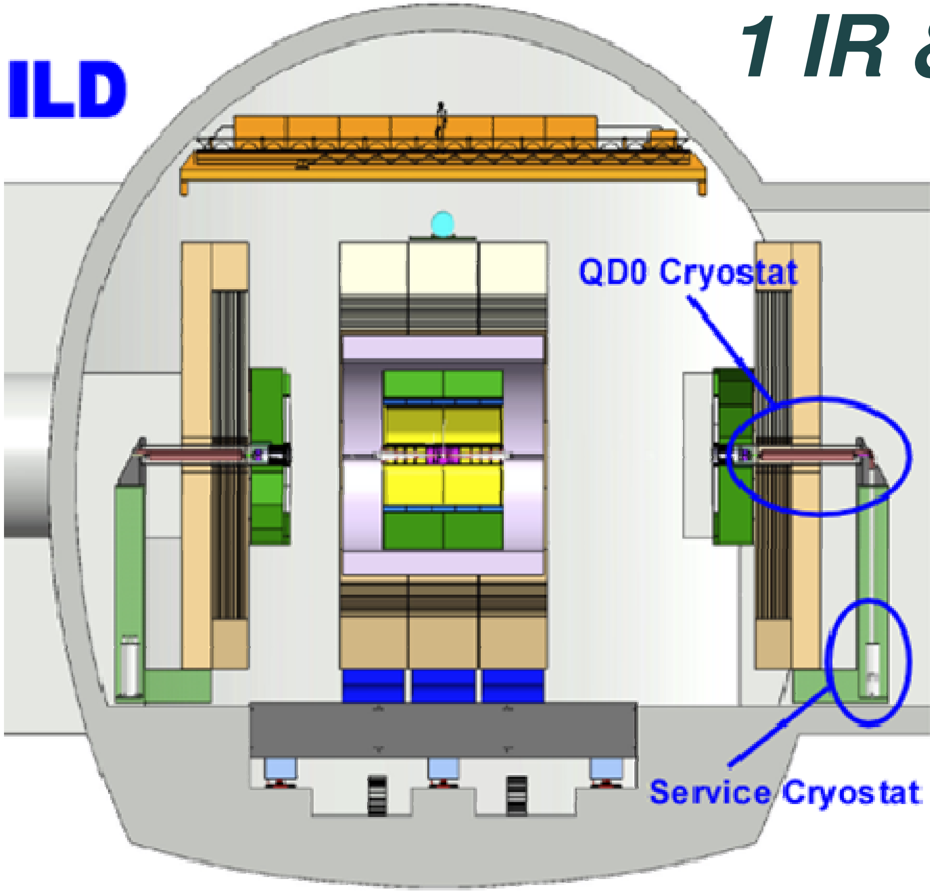
*Fig. 2. a) The number of trapped antihydrogen atoms per attempt, as a function of confinement time. The error bars represent uncertainties from counting statistics only. b) The statistical significance of the observed signal against the (cosmic-ray) background-only hypothesis, expressed in terms of the number of Gaussian standard deviations for a one-sided limit. (The point for 0.4s (>> 20σ) is off scale.) (ALPHA collaboration 2011.)*

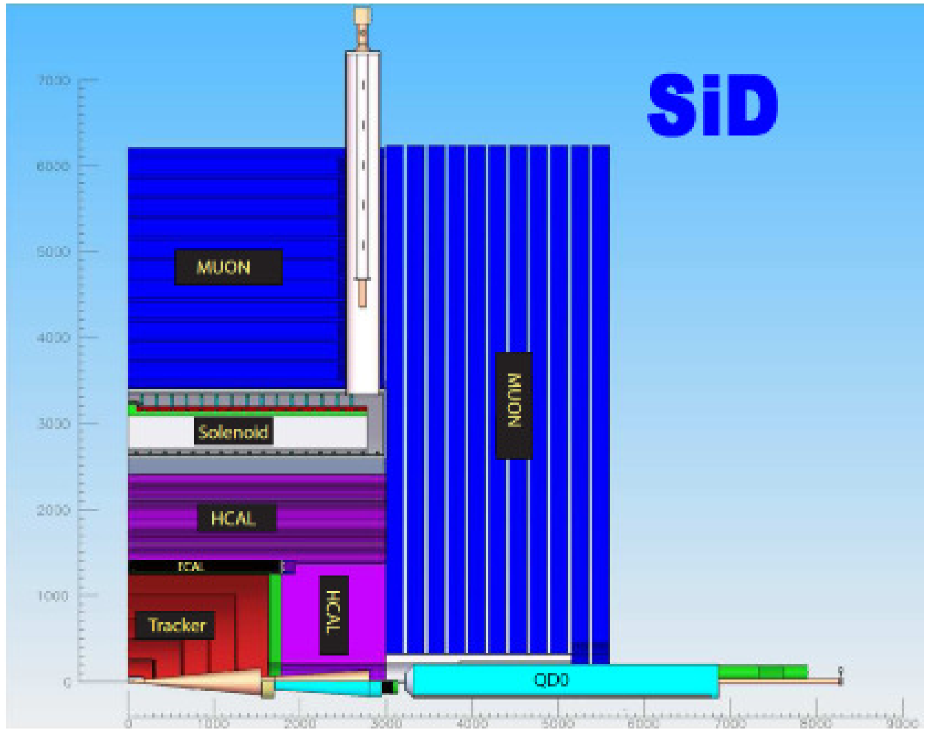
• **Further reading**
ALPHA collaboration 2011 *Nature Physics*. doi:10.1038/nphys2025.

# QD0 and the ILC Experimental Detectors

BROOKHAVEN NATIONAL LABORATORY
Superconducting Magnet Division

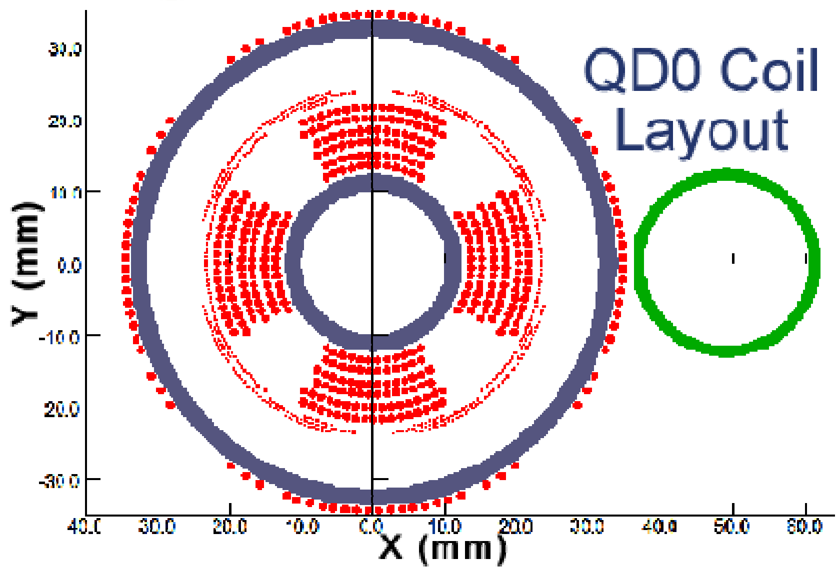
## *1 IR & 2 Push-Pull Detectors*



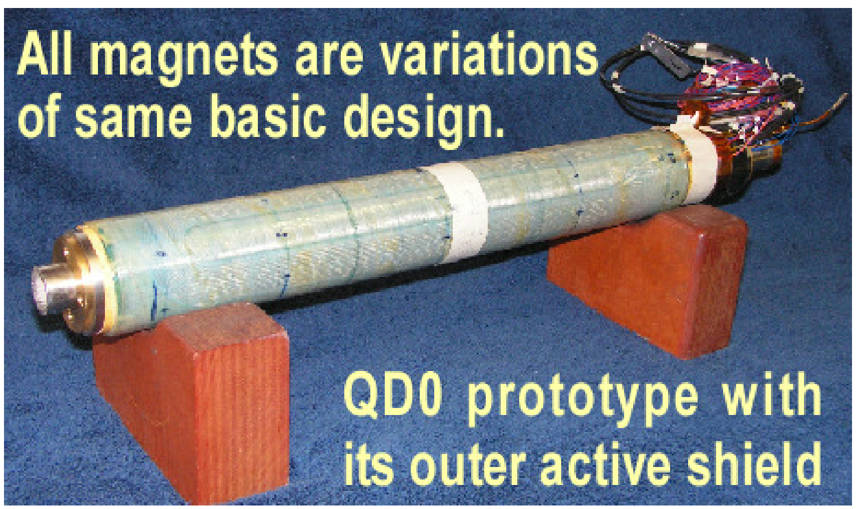



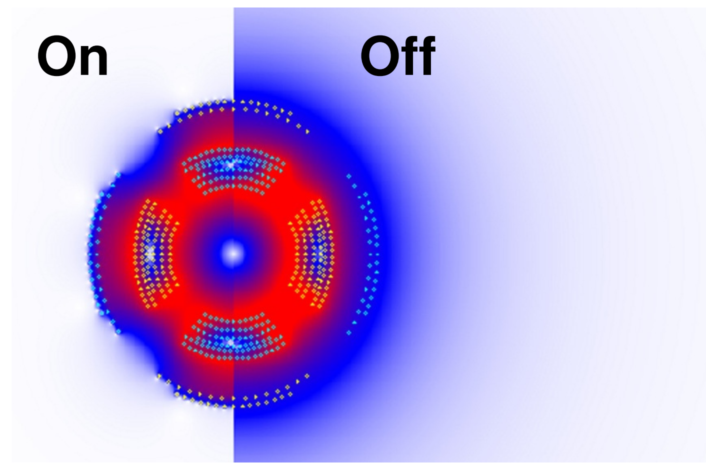

***QD0 sits inside the ILD (3.5 T) & SiD (5. T) detectors.***

# Design for Compact Superconducting Magnet Used in the ILC 14 mr Layout.



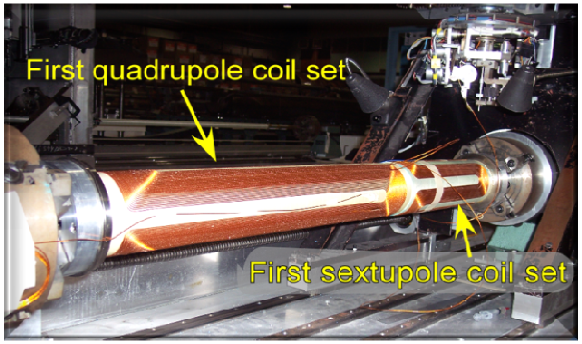

- 14 mr crossing angle via compact self-shielded QD0 coil windings.
- Extracted beam passes just outside coil into separate focusing channel.
- Cryostat to fit within limited space inside detector at L* = 3.5 to 4.5 m.

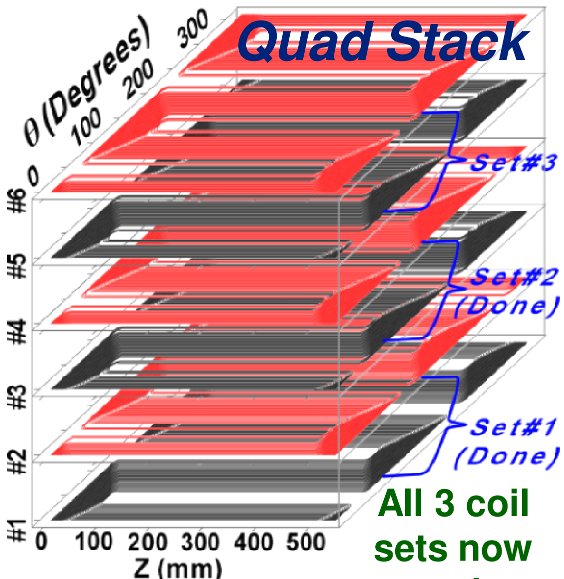



***QD0 with active shield on/off***

# Magnetic Measurements & Field Quality




All 3 coil sets now complete

***ATF2 Production***

- When we need to meet the most demanding field quality goals in a multilayer coil, we make warm harmonic measurements after each coil set is completed and then perform corrections to subsequent coil sets based upon these intermediate results.
- A good example is the ATF2 superconducting upgrade final focus magnet coil production.

# Summary of Integral Field Quality in ATF2 Magnet

| | Quadrupole | Sextupole |
|---|---|---|
| I.T.F. | 26.959 | 194.00 |
| Fld. Ang. (mr) | -12.5 | 14.8 |
| Leff(m) | -- | -- |
| b1 | -- | -1.6 |
| b2 | 10000.0 | -- |
| b3 | 0.49 | 10000.0 |
| b4 | -0.20 | 0.3 |
| b5 | 0.025 | -0.133 |
| b6 | 0.018 | 0.006 |
| b7 | 0.000 | 0.005 |
| b8 | 0.000 | 0.004 |
| b9 | 0.000 | 0.002 |
| b10 | 0.000 | 0.000 |
| b11 | 0.000 | 0.000 |
| b12 | 0.000 | 0.000 |
| b13 | 0.000 | 0.000 |
| b14 | 0.000 | 0.000 |
| b15 | 0.000 | 0.000 |
| a1 | -- | -53.8 |
| a2 | -- | -- |
| a3 | -0.49 | -- |
| a4 | -0.35 | -0.79 |
| a5 | -0.016 | -0.238 |
| a6 | 0.001 | -0.270 |
| a7 | 0.002 | -0.010 |
| a8 | 0.001 | 0.002 |
| a9 | 0.000 | 0.001 |
| a10 | 0.000 | 0.000 |
| a11 | 0.000 | 0.000 |
| a12 | 0.000 | 0.000 |
| a13 | 0.000 | 0.000 |
| a14 | 0.000 | 0.000 |
| a15 | 0.000 | 0.000 |

- We calculated harmonics for $R_{ref}$ = 10 mm to compare to the present ATF2 magnets.
- The poorest quad harmonics (b3,a3), are only **49. parts per million**.
- The areas highlighted in blue are all **smaller than 200 parts per billion**.

**Summary of Integral Field Quality in ATF2 Magnet (QH0LC5)**

Harmonics are in "Units" of $10^{-4}$ of the main field at 10 mm radius

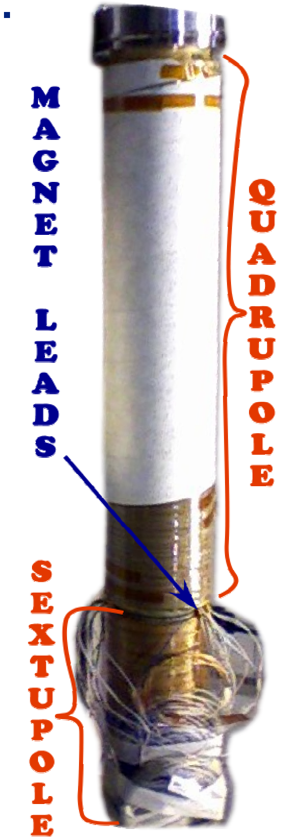
Harmonics reported are as seen from the lead ends of respective magnets

(This also accounts for the opposite sign of field angle in the two magnets)

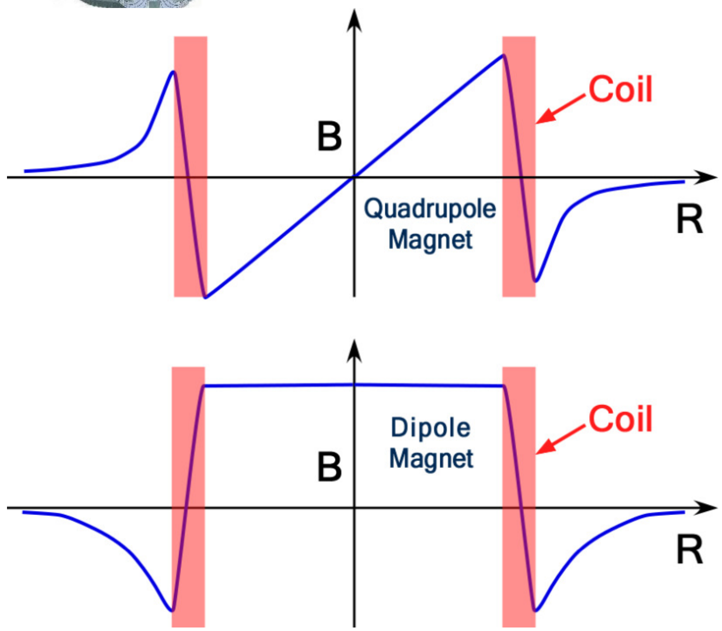
I.T.F for Quadrupole is in T/kA; ITF for Sextupole is in T/m/kA

(Integral of B" in sextupole is two times the value reported for the I.T.F)

## ATF2 Coils



# A Combined Function Magnet Trick.

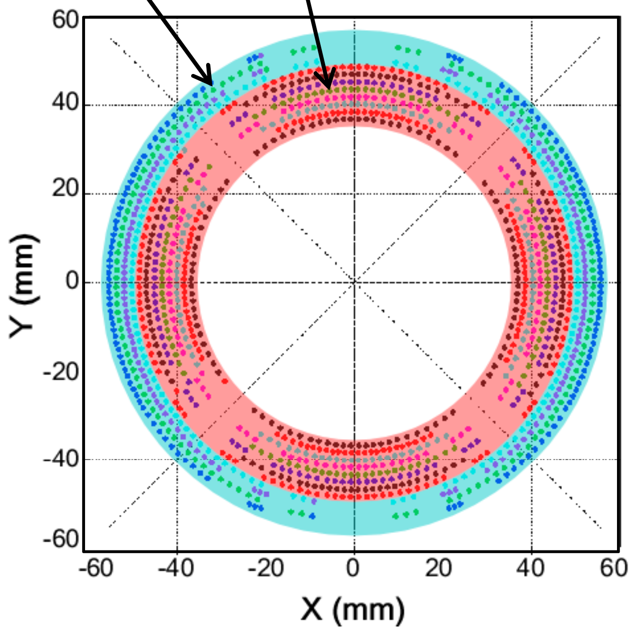



Observe the following generic behavior of the field with coil dominated magnet geometry, the field strength reverses crossing the coil structure and falls of rapidly outside the coil.

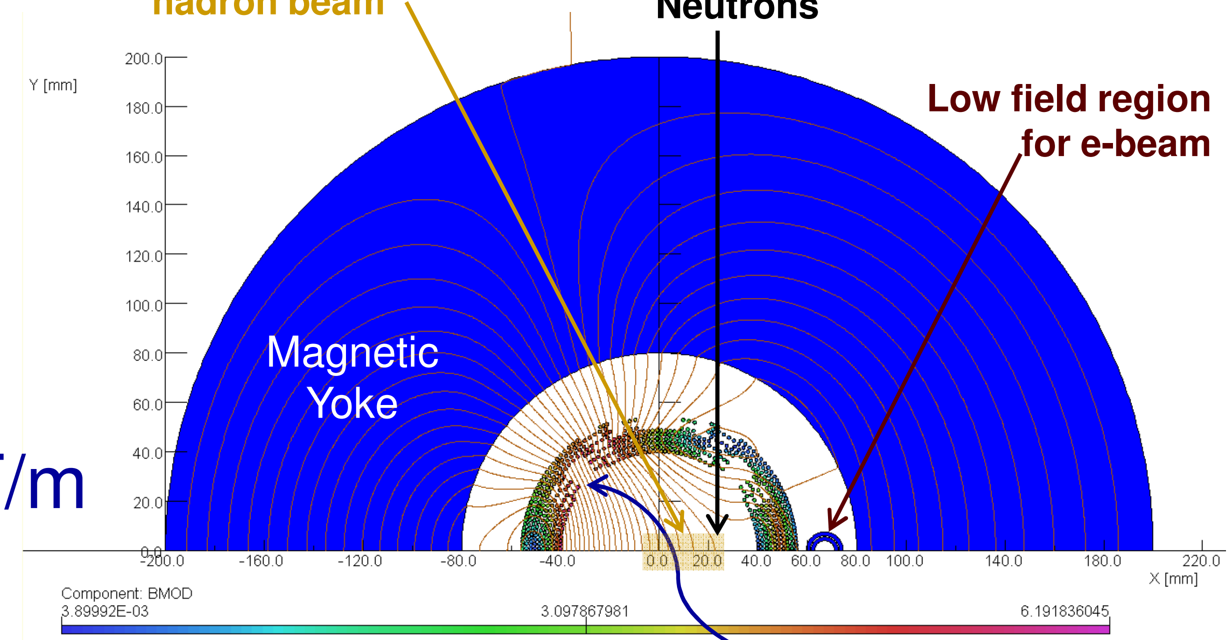
Thus on one side the combined external field is enhanced but on the other side the fields tend to cancel; with a careful choice of relative strengths and polarities we can create a low field region just outside the coil structure for the e-beam to pass.

# Design Details for First IR Magnet

*Dipole & Quadrupole Coil Sets*




- Magnet structure is aligned with e-beam.
- Magnet offset is optimized for neutrons, circulating beam and early analysis for off-momentum charged particle measurement.

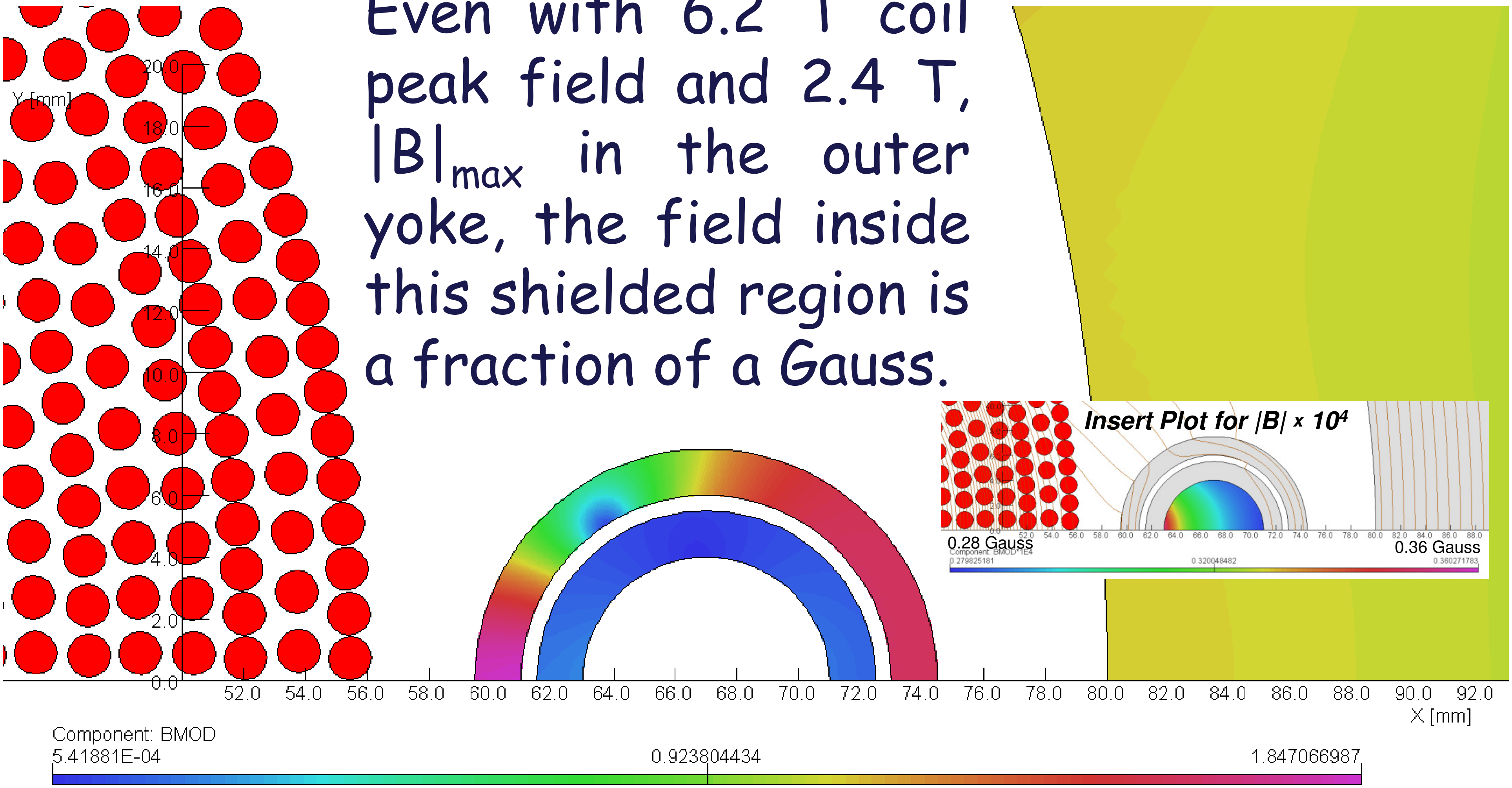



*Plot of |B| (Tesla) for the Coil Structure*

$B_o$ = 2.701 T
Gradient = -85.74 T/m
and $L_{mag}$ = 1.95 m

# Reduced Field Region for e-Beam

Even with 6.2 T coil peak field and 2.4 T, $|B|_{max}$ in the outer yoke, the field inside this shielded region is a fraction of a Gauss.



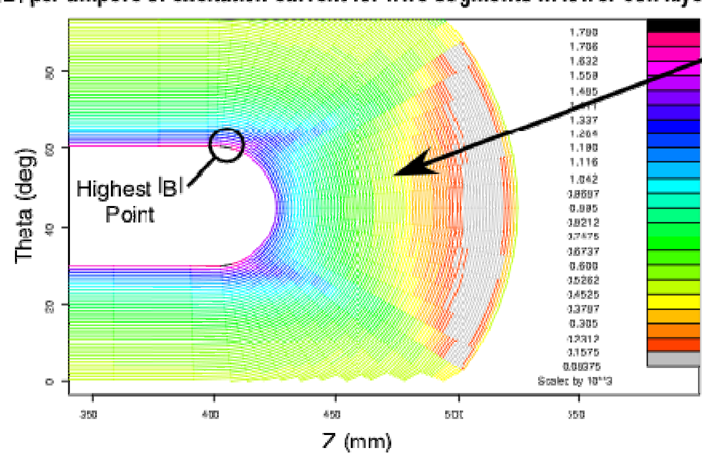

***Plot of |B| (Tesla) for the Yoke and Two Layer Shield Structure***

# BES-III: Peak Field in IR Quad Coil*

This BEPC-II peak field calculation is one way Pat helped turn bring my crazy Serpentine idea to fruition.
B. Parker, 15 September 2011

Our *Coilfield* code calculates the field contribution from each wiring segment defined in the winding pattern. By convention wiring segments are kept shorter than 0.5" (12.7 mm) and span no more than a 3° arc. *Coilfield* is used to calculate central and integral harmonics and transfer functions. We also can place the coil in a background field and calculate the total field, force and torque on each wire segment.

|B| per ampere of excitation current for wire segments in lower coil layer.



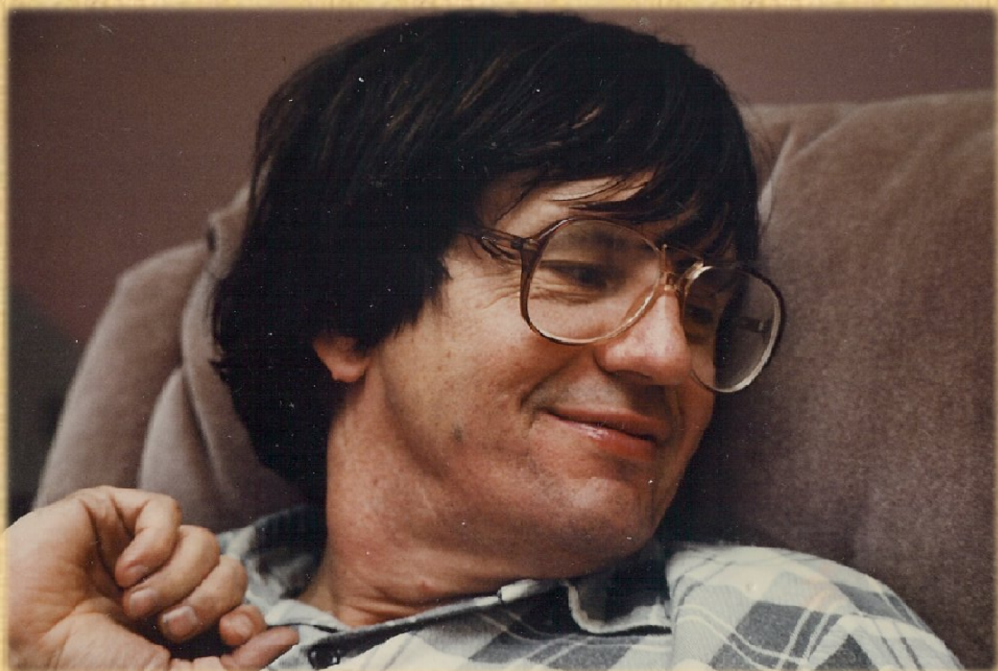

**Plot of total field at each wire segment in the wiring file with the highest field point shown in black.**

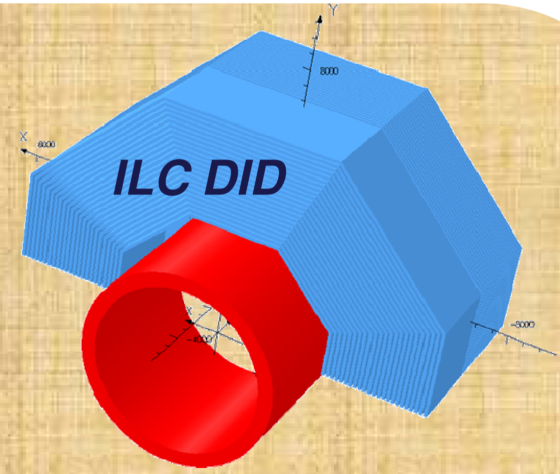
## Trivia:

**Note that for the eight winding layers for SCQ, such a calculation involves close to a quarter of a million wire segments.**

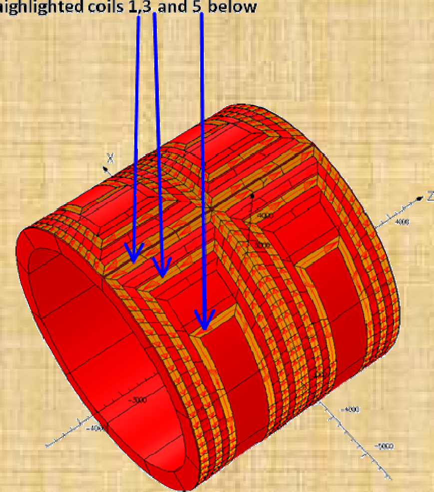
*Pat Thompson is primary author of the codes, Wire2Dopt, WireEndOpt, FlatPatternGen, SerpentineGen, Coilfield, CoilPlot and CoilForce among with many other BNL codes.

# How far will we take BNL Direct Wind?

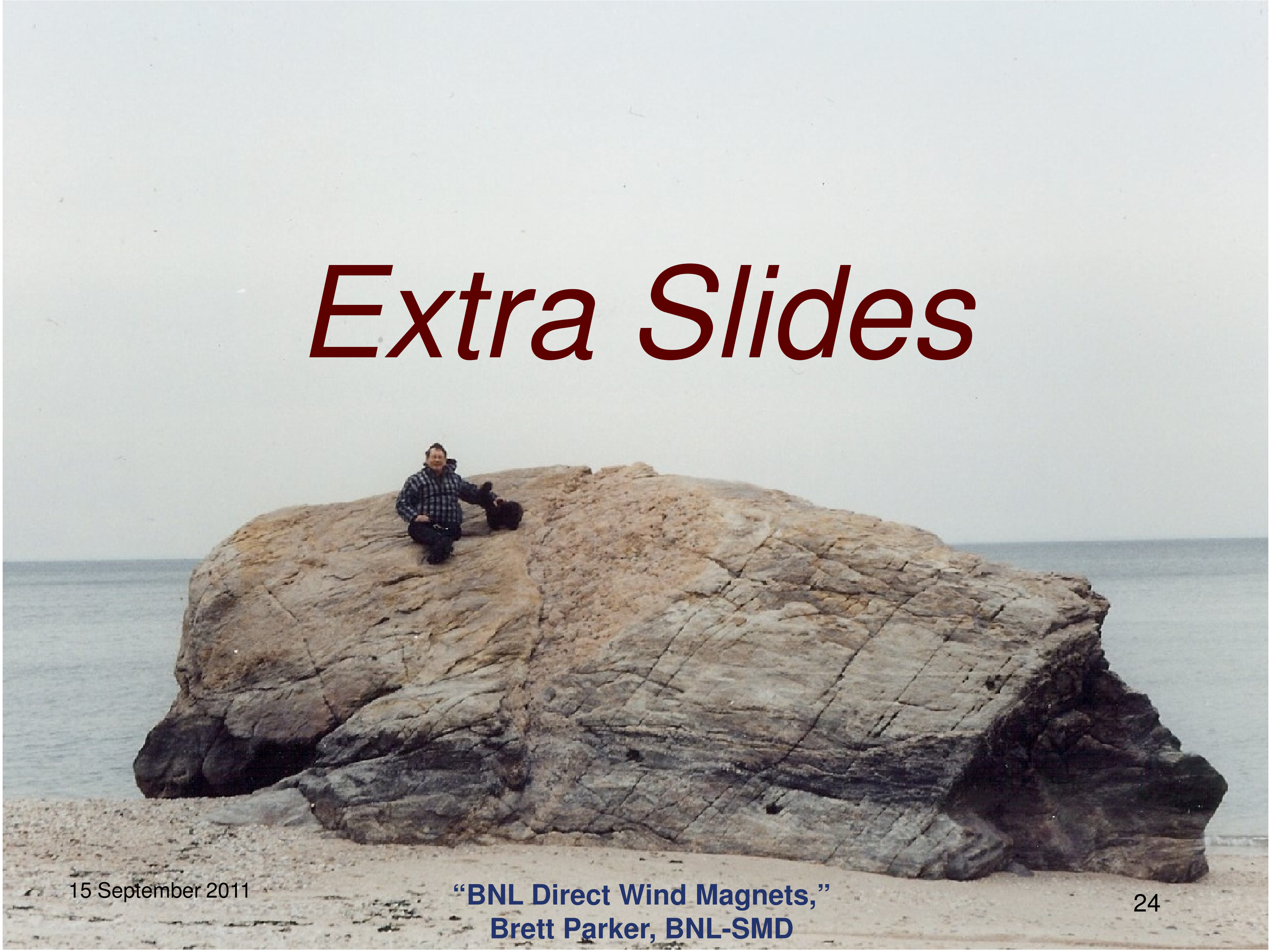





The DID has five coils, where I have highlighted coils 1,3 and 5 below



Adieu Pat.

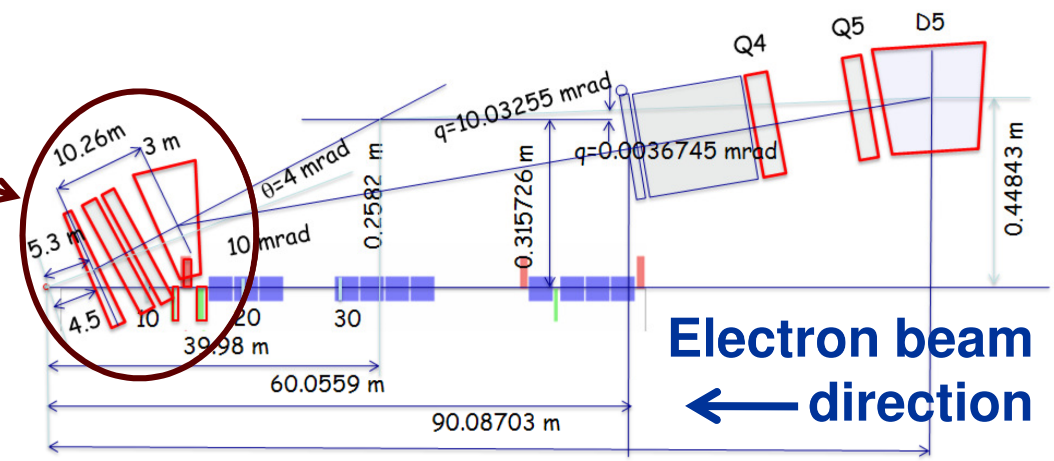


# *Extra Slides*

# IR Configuration for eRHIC

Critical magnets with requirements coming from both accelerator and detector physics.

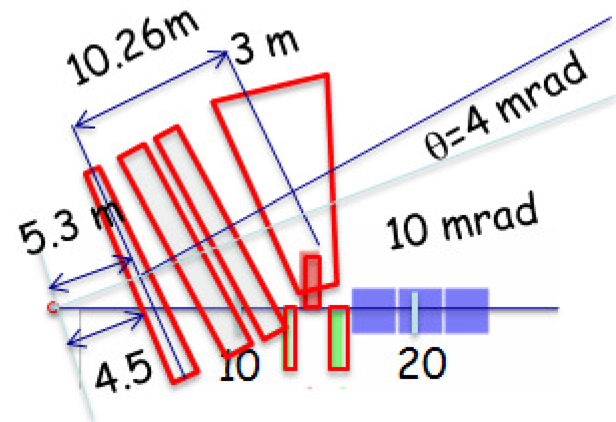
***eRHIC IR Magnets for Hadrons Downstream (Electrons Upstream)***




- Look to bring e-beam to IP while keeping "strong" bends far away (minimize Synrad related backgrounds).
- Provide good experimental acceptance and separate neutrons and other off-momentum charged particles from the outgoing hadron circulating beam.

# First IR Magnet Considerations

- Must provide low-field region, 10 mr away from hadron beam, for incoming e-beam.
- Strong beam focusing + large solid angle for detection → superconducting magnet.
- For compact optics solution with tailored deflection and separation of off-momentum particles → use combined function magnet.

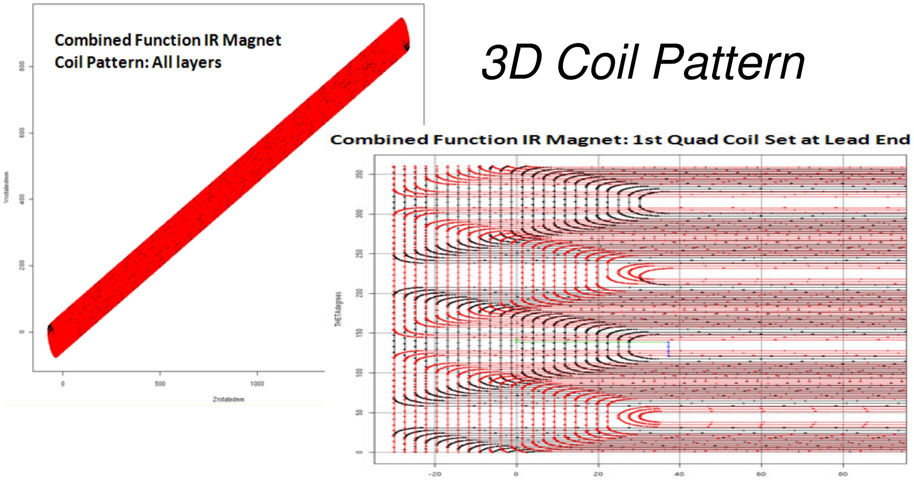


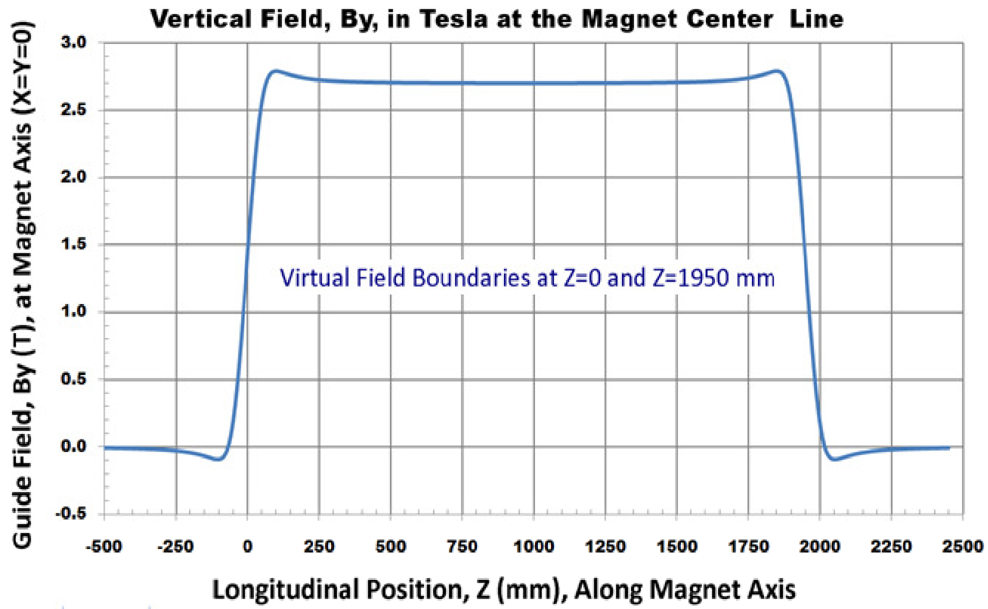

Note 4.5 m β*

**Above implies fairly high coil peak fields (at least compared to iron saturation); how can we create a low field pocket for the e-beam to get to the IP?**

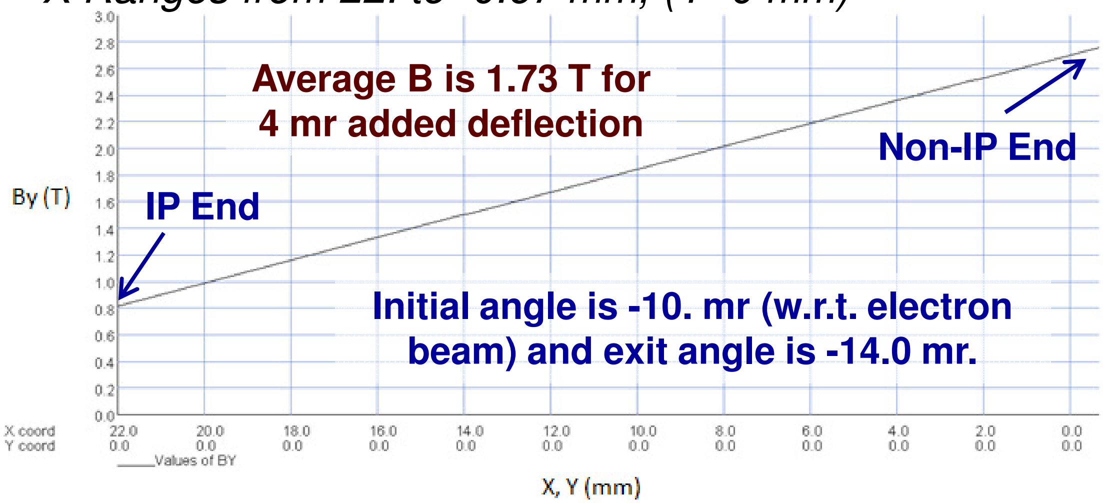
# eRHIC Magnet 2D and 3D Field Profiles

*3D Coil Pattern*



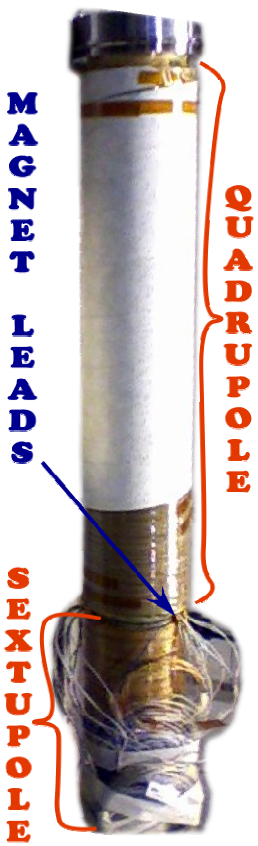

*On Axis Field, By(T), Seen by Hadron Beam*
*X Ranges from 22. to -0.67 mm, (Y=0 mm)*




**3D field is calculated via rescaling of the "bare coils" using the 2D results. For final design we need full calculations and to optimize the shielding to take into account end-field effects.**

# Summary of Integral Field Quality in ATF2 Magnet

## ATF2 Coils



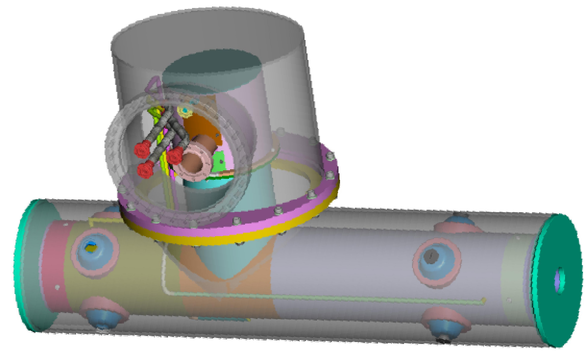

| Normal | Quadrupole | Sextupole |
|---|---|---|
| I.T.F. | 26.959 | 194.00 |
| Fld. Ang. (mr) | -12.5 | 14.8 |
| Leff(m) | -- | -- |
| b1 | -- | -0.3 |
| b2 | 10000.0 | -- |
| b3 | 1.2 | 10000.0 |
| b4 | -1.3 | 0.6 |
| b5 | 0.4 | -0.8 |
| b6 | 0.7 | 0.1 |
| b7 | 0.0 | 0.2 |
| b8 | -0.1 | 0.4 |
| b9 | 0.0 | 0.4 |
| b10 | 0.0 | 0.1 |
| b11 | 0.0 | 0.5 |
| b12 | 0.0 | 0.1 |
| b13 | 0.0 | 0.0 |
| b14 | 0.0 | -0.1 |
| b15 | 0.0 | -0.5 |

| Skew | Quadrupole | Sextupole |
|---|---|---|
| I.T.F. | 26.959 | 194.00 |
| Fld. Ang. (mr) | -12.5 | 14.8 |
| Leff(m) | -- | -- |
| a1 | -- | -8.6 |
| a2 | -- | -- |
| a3 | -1.2 | -- |
| a4 | -2.2 | -2.0 |
| a5 | -0.3 | -1.5 |
| a6 | 0.1 | -4.2 |
| a7 | 0.2 | -0.4 |
| a8 | 0.1 | 0.2 |
| a9 | 0.1 | 0.3 |
| a10 | -0.2 | 0.2 |
| a11 | 0.0 | 0.1 |
| a12 | 0.0 | -0.2 |
| a13 | 0.0 | -0.1 |
| a14 | 0.0 | 0.0 |
| a15 | 0.0 | 0.0 |

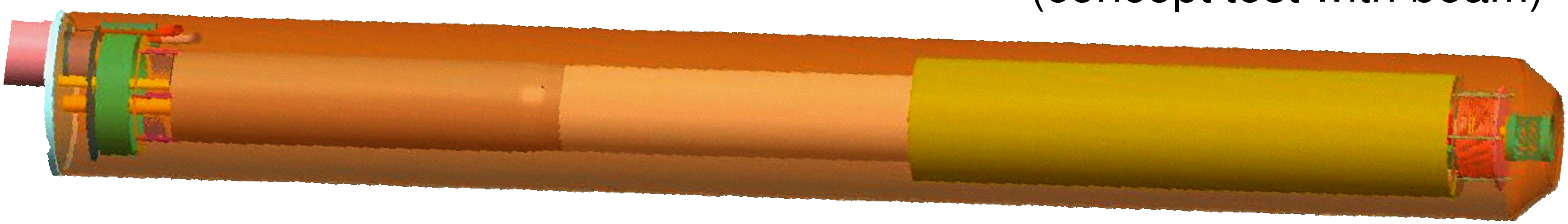
**Harmonics are in "Units" of $10^{-4}$ of the main field at 25 mm as seen from the lead ends of respective magnets (yielding opposite sign of field angle in the two magnets). I.T.F for Quadrupole is in T/kA; ITF for Sextupole is in T/m/kA (Integral of B'' in sextupole is two times the value reported for the I.T.F).**

# ILC R&D Prototype and ATF2 Comparison

- Both are compatible with 1.9K testing via an ILC-style Service Cryostat (SC) at BNL.
- The ATF2 magnet can be tested with beam; there is no way to beam test R&D prototype.

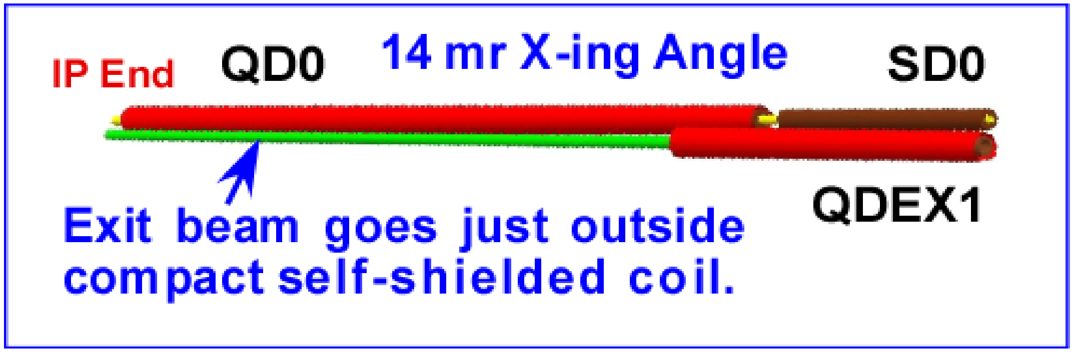


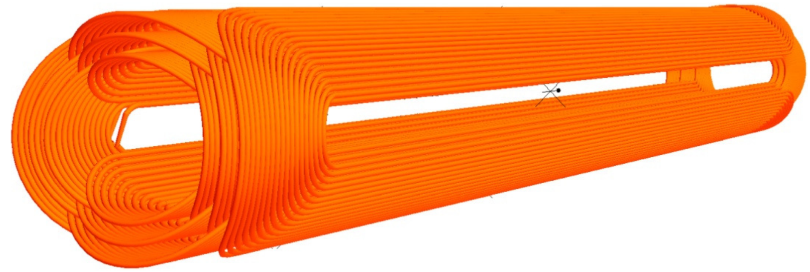
ATF2 Upgrade Magnet
(concept test with beam)



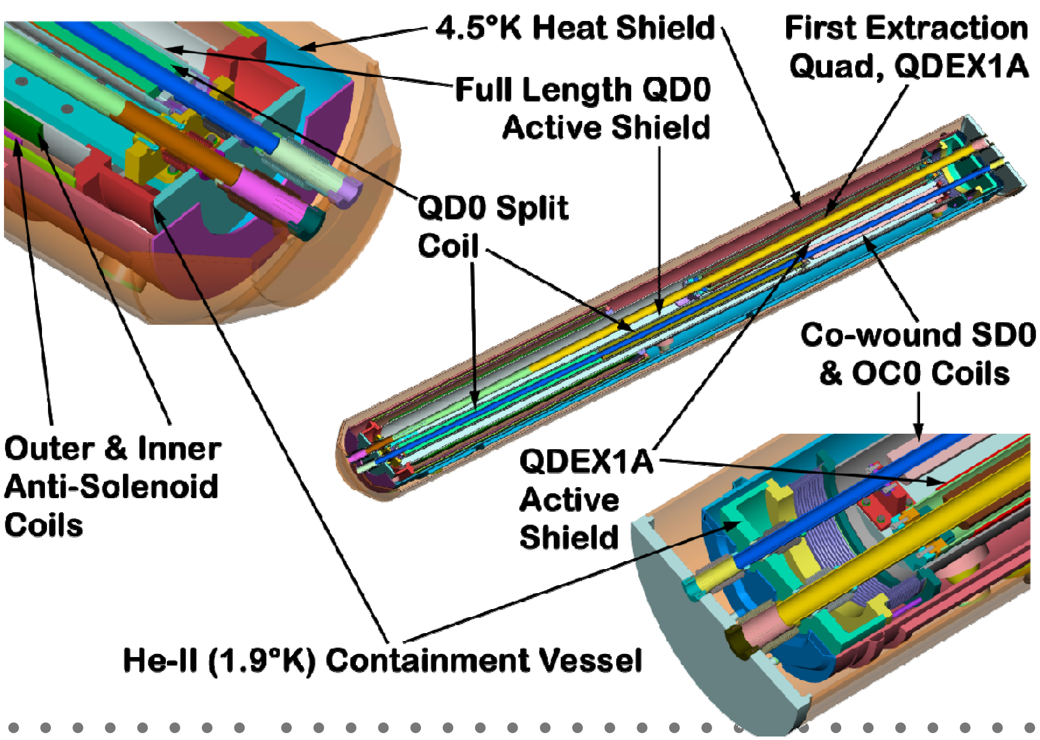
ILC QD0 Full-Length R&D Prototype Magnet Program
(a full-scale, instrumented, 1.9K ILC SC, systems test)

# ILC 14 mr Crossing Angle Magnet Details



***QD0 Coils in Opera3d***

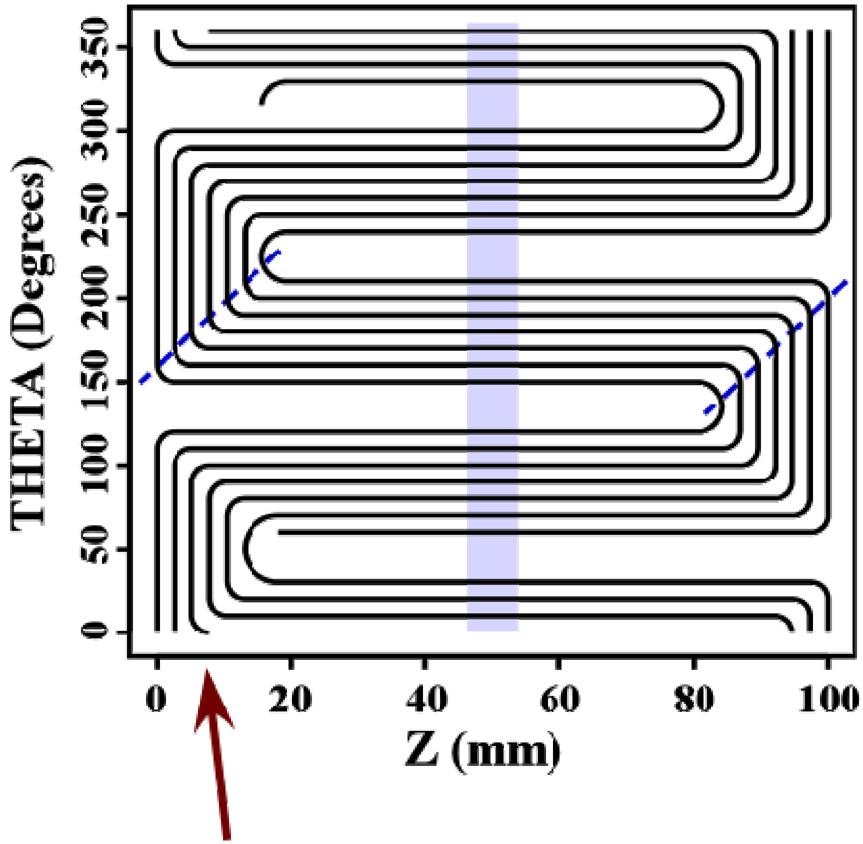



The QD0 magnet cryostat contains multiple actively shielded quadrupole coils, with sextupole and octupole coils, many correction coils plus an adjustable force-neutral anti-solenoid.

# Constant bend radius Serpentine turns for integral harmonics identical to 2D



**angular and longitudinal turn offsets do not change the result.**



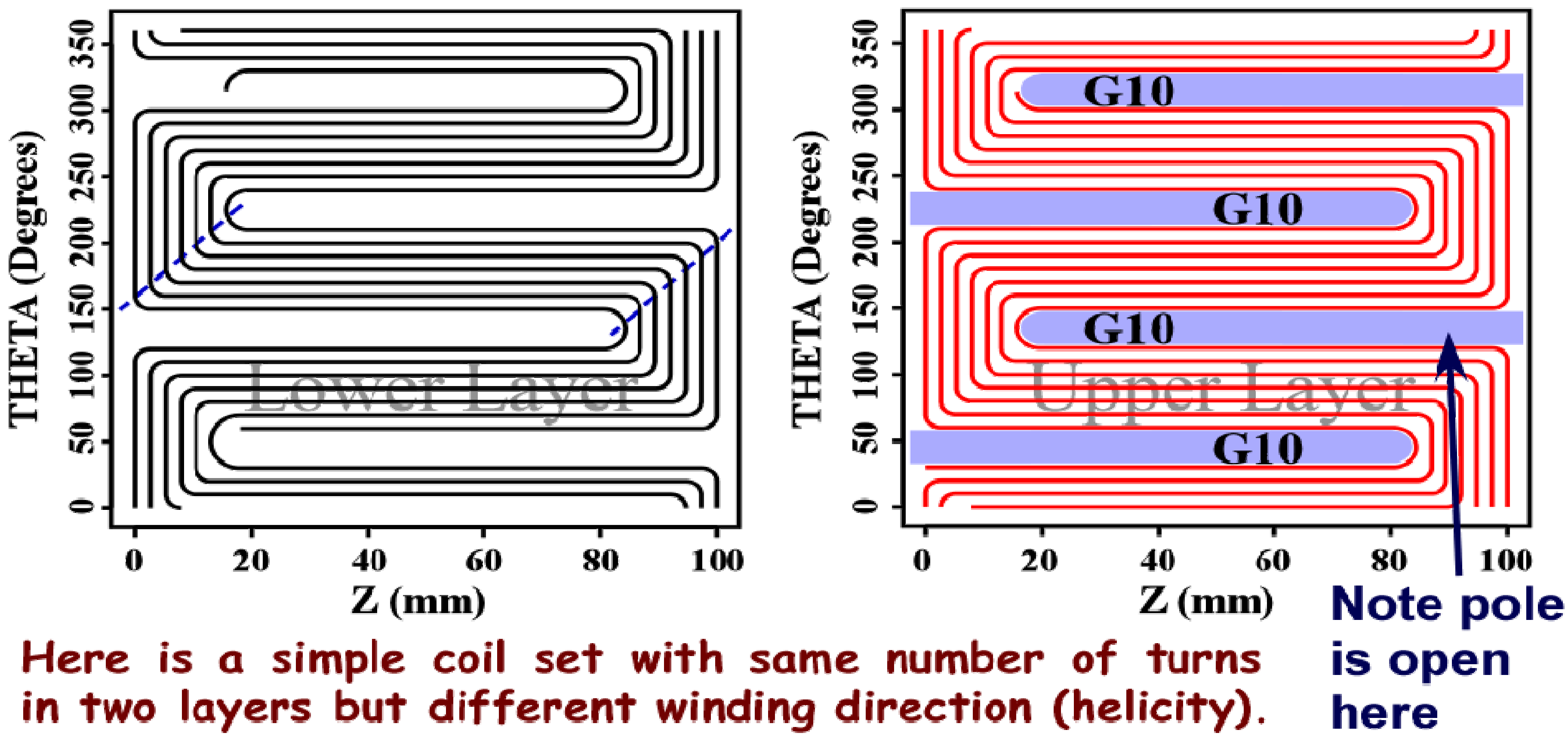

Adjusting integral harmonics then becomes very simple; optimize 2D cross section (blue band) and the integral harmonics will be the same... except for the N to N+1 effect.

The need to connect turn N to turn N+1 means that one coil pack must be slightly different from the rest and this drives allowed and unallowed harmonics. For a short enough magnet this effect is noticeable; but then just modulate the 2D cross section to put in a counter term (what you put in is what you get).

**Note constant end spacing for very simple construction.**

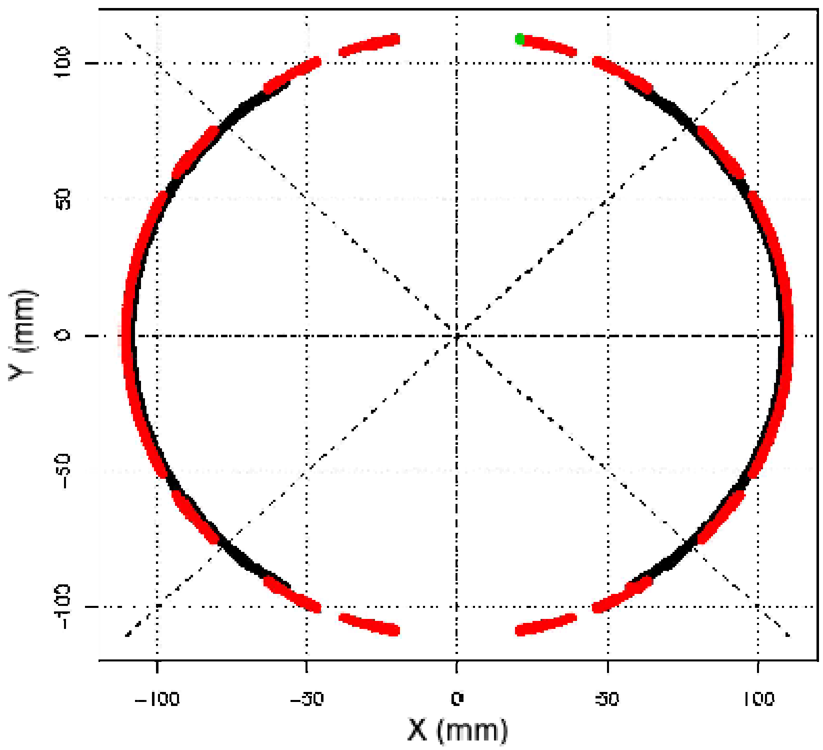
# Some Observations With Respect to Winding Serpentine Coil Sets

A single layer N-turn Serpentine winding wraps around the support tube N times and produces solenoidal field. To avoid this make sure to wind opposite way in other layers (no net winding around the tube).

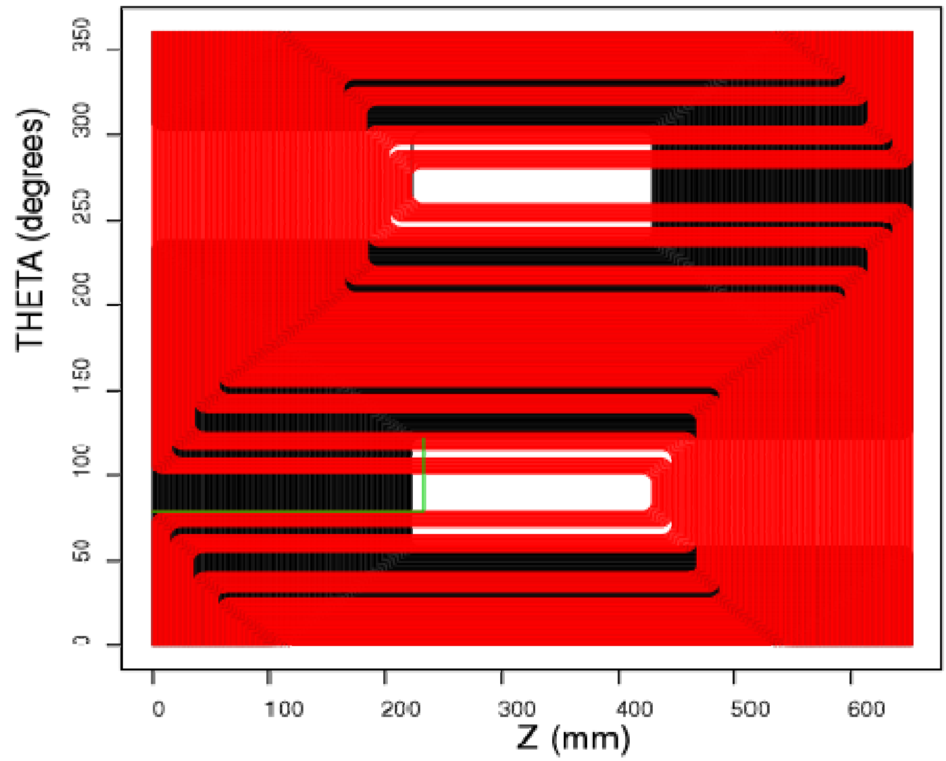



Here is a simple coil set with same number of turns in two layers but different winding direction (helicity).

# Final SCB Serpentine Coil Pattern.



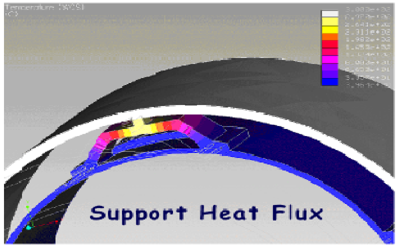
SCB Final Serpentine Cross Section

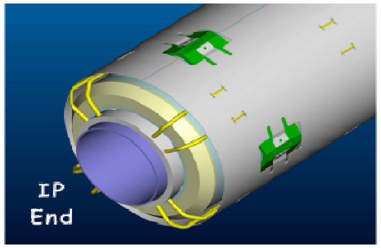


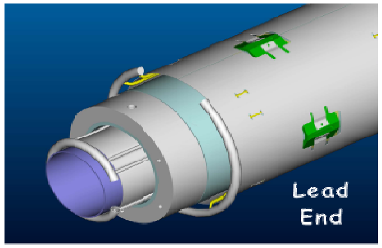
SCB Final Serpentine Winding Pattern

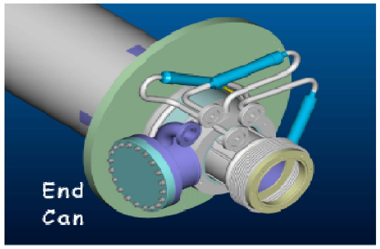
Like SCQ the SCB coil is wound from seven strand cable. Here three spacers in the upper layer are sufficient to ensure good harmonics. Note that dipole ends are naturally longer than quadrupole ends so SCB has even less "straight section" than SCQ and has to be wound longer than SCQ in order to have the same magnetic length.

# BEPC-II Design Details

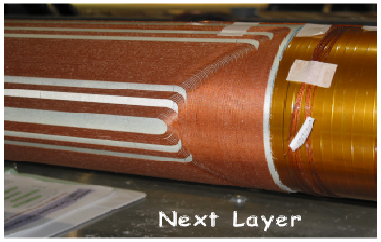


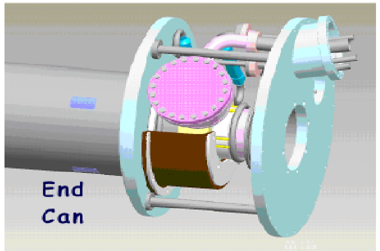






## Magnet Production for BEPC-II Upgrade

BEPC-II quadrupole field quality measurements (shown at right) meet specifications. First magnet was tested vertically with all coils energized simultaneously at least 10% above operating values (worst case $B_{peak}$ i.e. without subtraction of BES-III 1T and dipole in Synrad mode) without quenching. The final magnet will be cold tested soon.

**Summary of Field Quality in BEPC Quads**

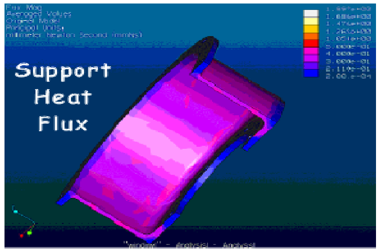
**Warm measurements after completing the skew layers**

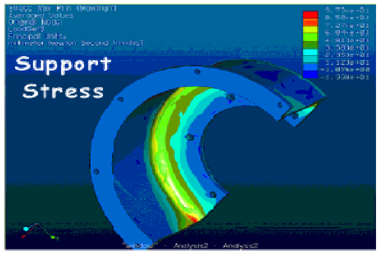
Harmonics are in "units" of $10^{-4}$ at 50 mm radius

| | Magnet 1 (QHG202) Run 31 | Magnet 2 (QHG203) Run 24 | | Magnet 1 (QHG202) Run 31 | Magnet 2 (QHG203) Run 24 |
|---|---|---|---|---|---|
| ITF (T/kA) | 15.73 | 15.77 | | --- | --- |
| $b_3$ | 0.35 | 1.80 | $a_3$ | -1.28 | -1.63 |
| $b_4$ | -0.47 | 0.06 | $a_4$ | -1.26 | -0.53 |
| $b_5$ | 0.04 | -0.06 | $a_5$ | 0.05 | 0.05 |
| $b_6$ | 0.37 | 0.42 | $a_6$ | 0.04 | -0.09 |
| $b_7$ | 0.13 | 0.45 | $a_7$ | -0.18 | -0.34 |
| $b_8$ | -0.13 | -0.13 | $a_8$ | -0.08 | -0.11 |
| $b_9$ | -0.04 | -0.04 | $a_9$ | 0.05 | 0.06 |
| $b_{10}$ | -0.01 | 0.02 | $a_{10}$ | 0.05 | 0.04 |
| $b_{11}$ | -0.02 | -0.07 | $a_{11}$ | 0.03 | 0.06 |
| $b_{12}$ | 0.00 | 0.00 | $a_{12}$ | 0.00 | 0.01 |
| $b_{13}$ | 0.00 | 0.00 | $a_{13}$ | 0.00 | 0.00 |
| $b_{14}$ | -0.03 | -0.03 | $a_{14}$ | 0.00 | 0.00 |
| $b_{15}$ | 0.00 | 0.00 | $a_{15}$ | 0.00 | 0.00 |

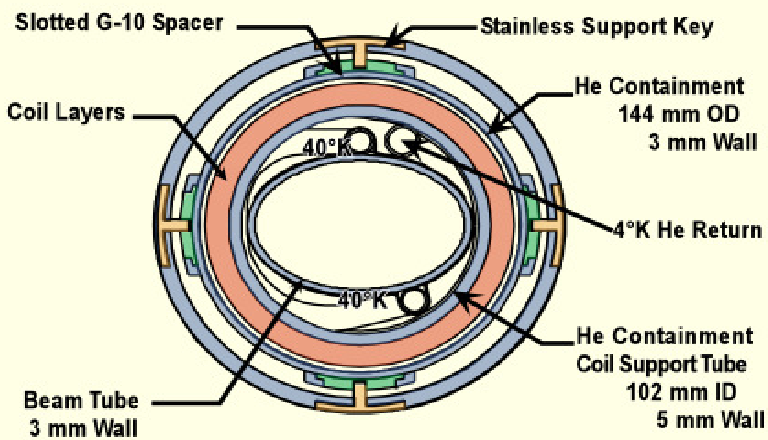
Note: $(b_n, a_n)$ are the normal and skew $2n$-pole terms in the harmonic expansion

Coil Pack: quad, dipole, skew-dipole, skew-quad and 3 solenoids

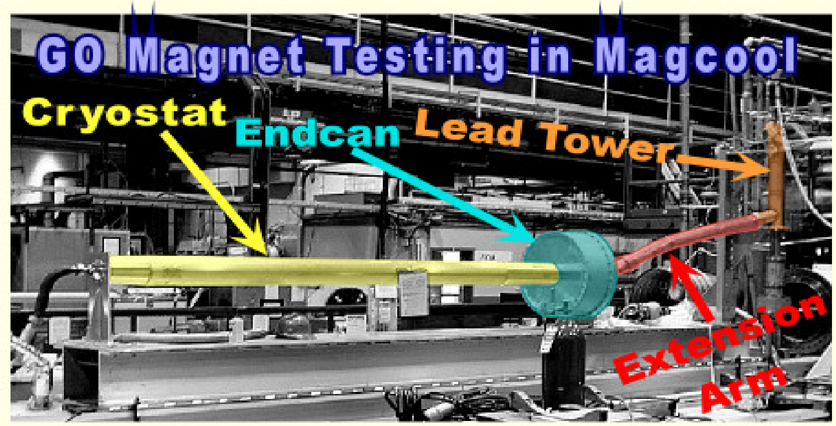


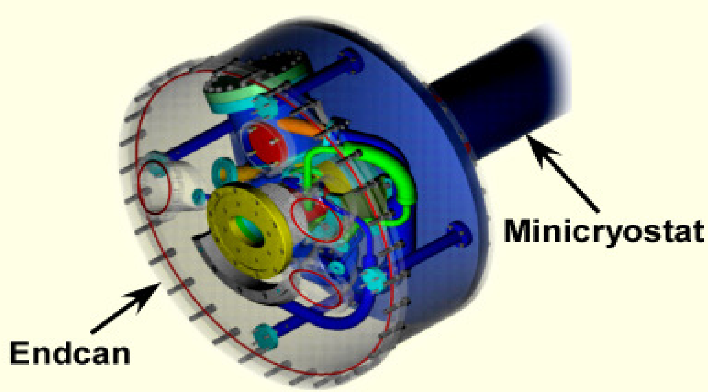



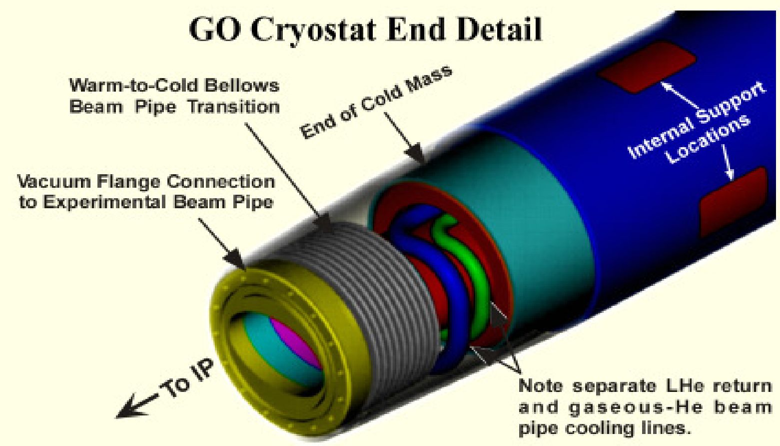
# HERA-II Cryostat Design Summary



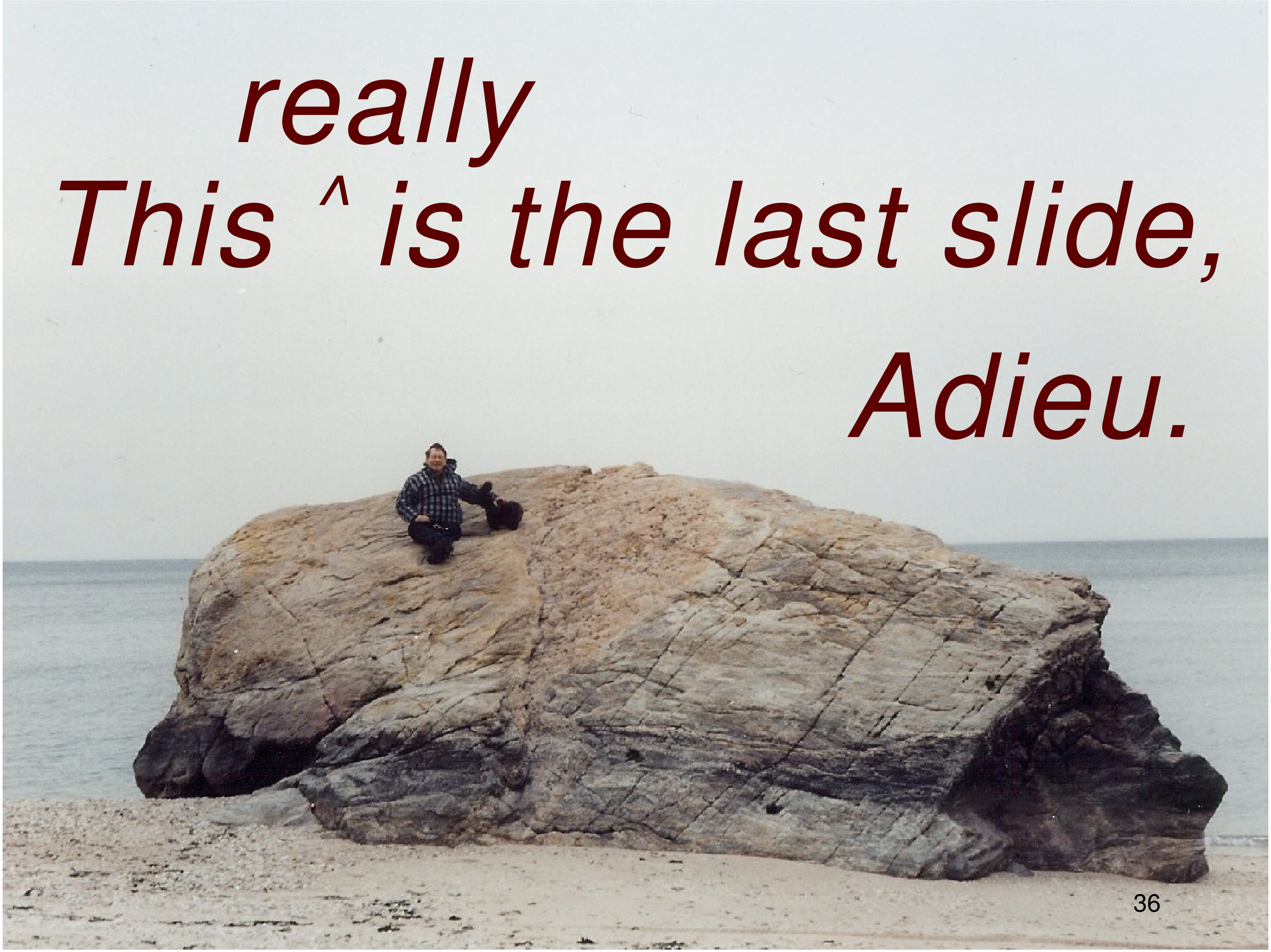

GO Thickened Cryostat Wall Section at Key Supports




**Design, Build and Test Magnets in "Mini" Cryostats**


really
This ^ is the last slide,
Adieu.