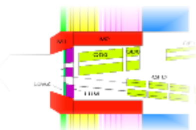
Linear Collider Final Focus Magnets

presented by,

Brett Parker, BNL–SMD



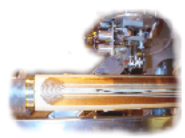
Snowmass 2001

HERA

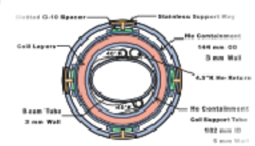
H1

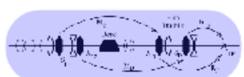
ZEUS

Linear Collider Final Focus Issues

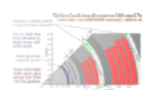


HERA and BEPC-II Upgrade Magnets

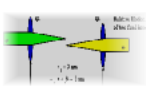




BEPC-II



Preliminary NLC FF Magnet Parameters



Design Challenges & Future Work

SLAC December 2001

Design Parameters

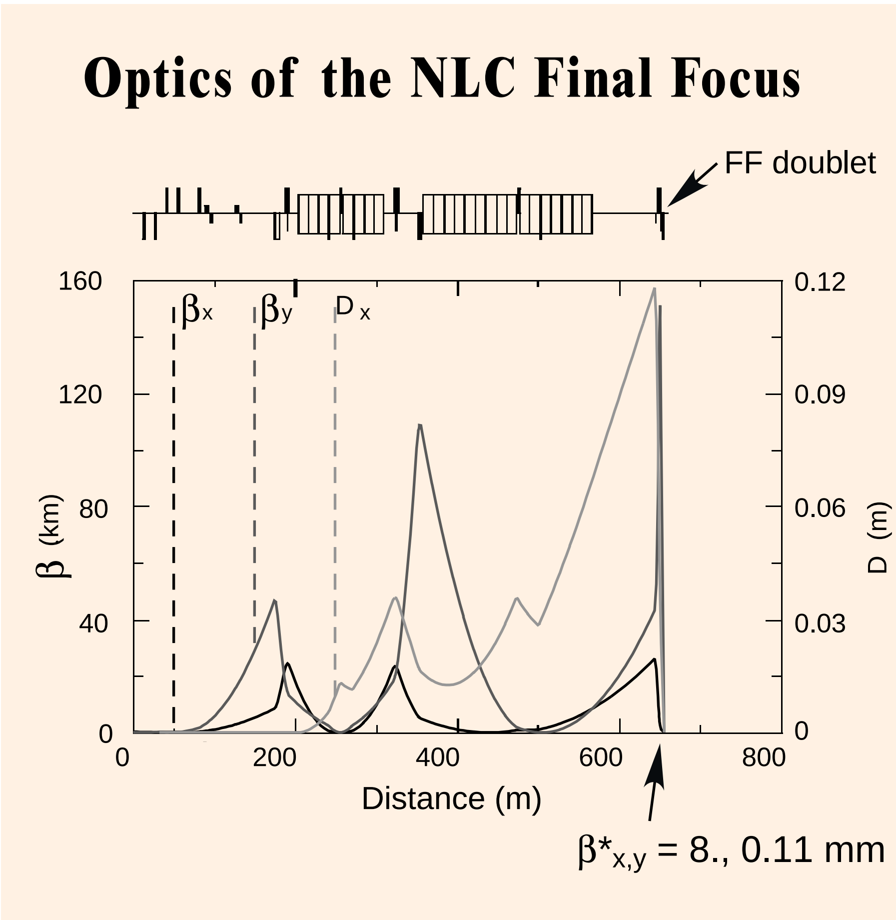
Post ISG (November 2001)

	Stage 1		Stage 2	
CMS Energy (GeV)	500		1000	
Site	US	Japan	US	Japan
Luminosity (10^{33})	**20**	**25**	**30**	**25**
Repetition Rate (Hz)	120	150	120	100
Bunch Charge (10^{10})	**0.75**		**0.75**	
Bunches/RF Pulse	192		192	
Bunch Separation (ns)	1.4		1.4	
Eff. Gradient (MV/m)	**48.5**		**48.5**	
Injected $\gamma\varepsilon_x / \gamma\varepsilon_y$ (10^{-8})	300 / 2		300 / 2	
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	360		360	
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	**4**		**4**	
β_x / β_y at IP (mm)	8 / 0.11		13 / 0.11	
σ_x / σ_y at IP (nm)	**243 / 3.0**		**219 / 2.3**	
θ_x / θ_y at IP (μr)	**32 / 28**		**17 / 20**	
σ_z at IP (μm)	110		110	
Υ_{ave}	0.14		0.29	
Pinch Enhancement	1.51		1.47	
Beamstrahlung δB (%)	5.4		8.9	
Photons per e+/e-	1.3		1.3	
Two Linac Length (km)	12.6		25.8	

Low Energy IP Parameters (8/00)			
CMS Energy (GeV)	**92**	**250**	**350**
Luminosity (10^{33})	**3.5**	**9.4**	**13.2**
Repetition Rate (Hz)	**120**	**120**	**120**
Bunch Charge (10^{10})	**0.75**	**0.75**	**0.75**
σ_x / σ_y at IP (nm)	**630 / 6.2**	**380 / 3.8**	**320 / 3.2**
L0 / Ltotal (%)	62	47	43
Beamstrahlung δB (%)	0.18	1.1	2
Photons per e+/e-	0.49	0.79	0.92
Polarization loss (%)	0.08	0.21	0.34

Tom Markiewicz

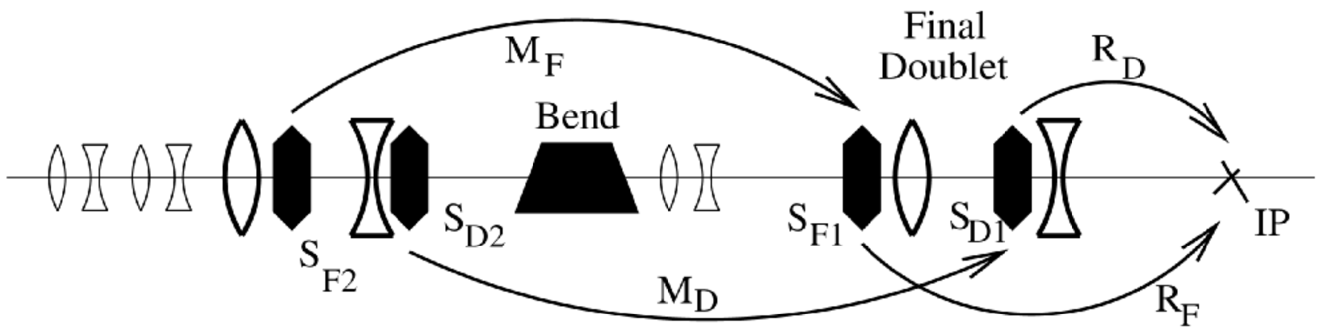
NLC Beam Delivery System: Final Focus Optics Summary.



- Extreme vertical demagnification at IP $(0.11\text{ mm} \div 150\text{ km})^{1/2} = 2.7 \times 10^{-5}$.
- Sextupoles needed to correct chromaticity (compensate for momentum spread).
- Beam sizes $\sigma_x/\sigma_y = 243./3.0$ nm at IP (but a few tenths of a mm in FF doublet).
- Small kicks in FF doublet can cause beams to miss each other (Y–offset sensitivity).

Raimondi/Seryi Final Focus Lattice

Local Chromaticity Compensation



- FF Design driven by need to compensate FD chromaticity

  Locally correct chromaticity by two sextupoles placed in FD with a bend upstream to generate dispersion across the FD.

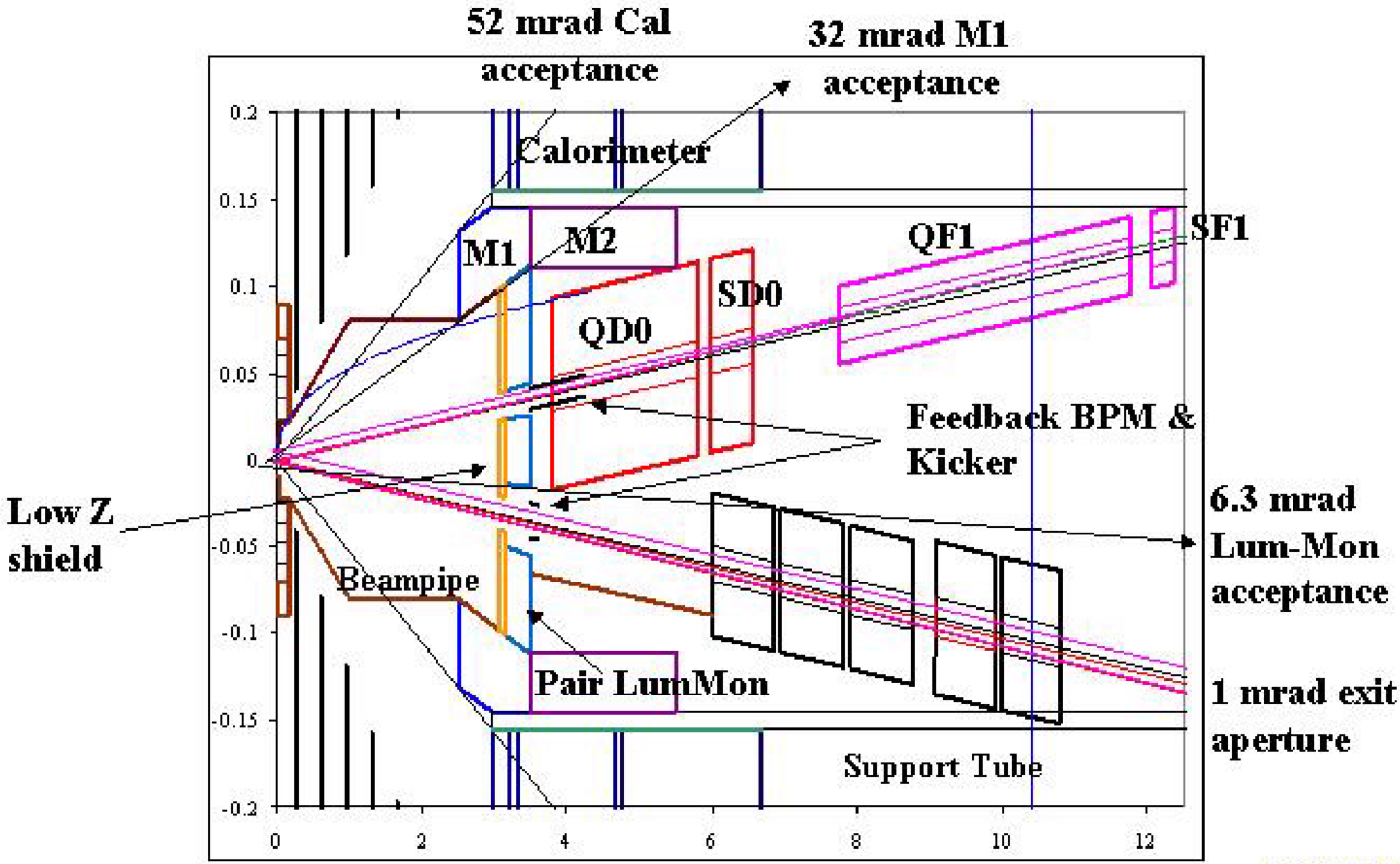
  Geometric aberrations of FD sextupoles are cancelled by two more sextupoles placed in phase with them and upstream of the bend.

  Four more quadrupoles are needed to match the incoming beam.

  Drop orthogonal tuning design constraint

LCD-L2 (3T) with 3.8m L* Optics

Separate (Easier?) Extraction Line θ_C=20 mrad



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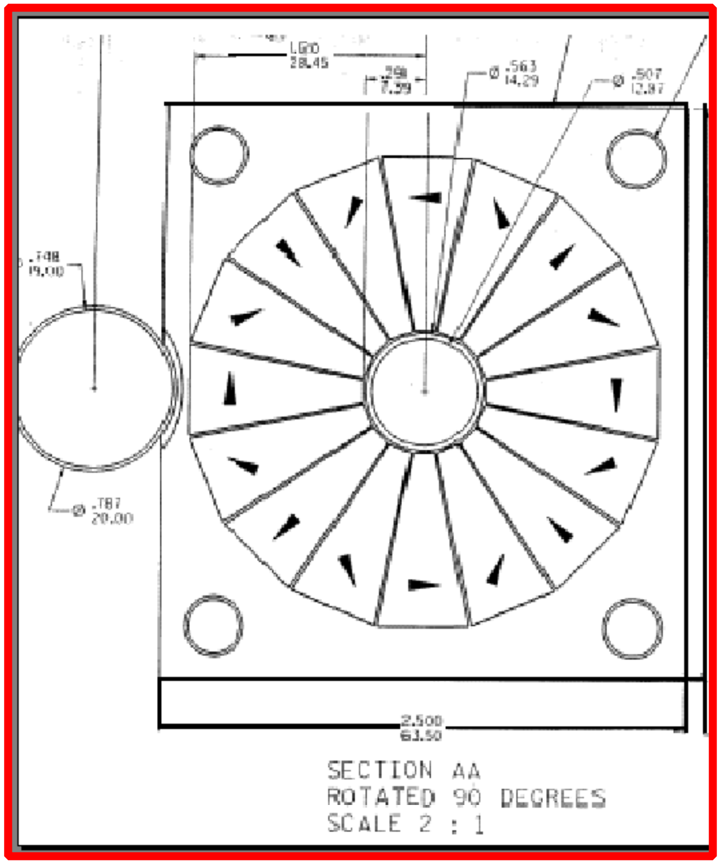
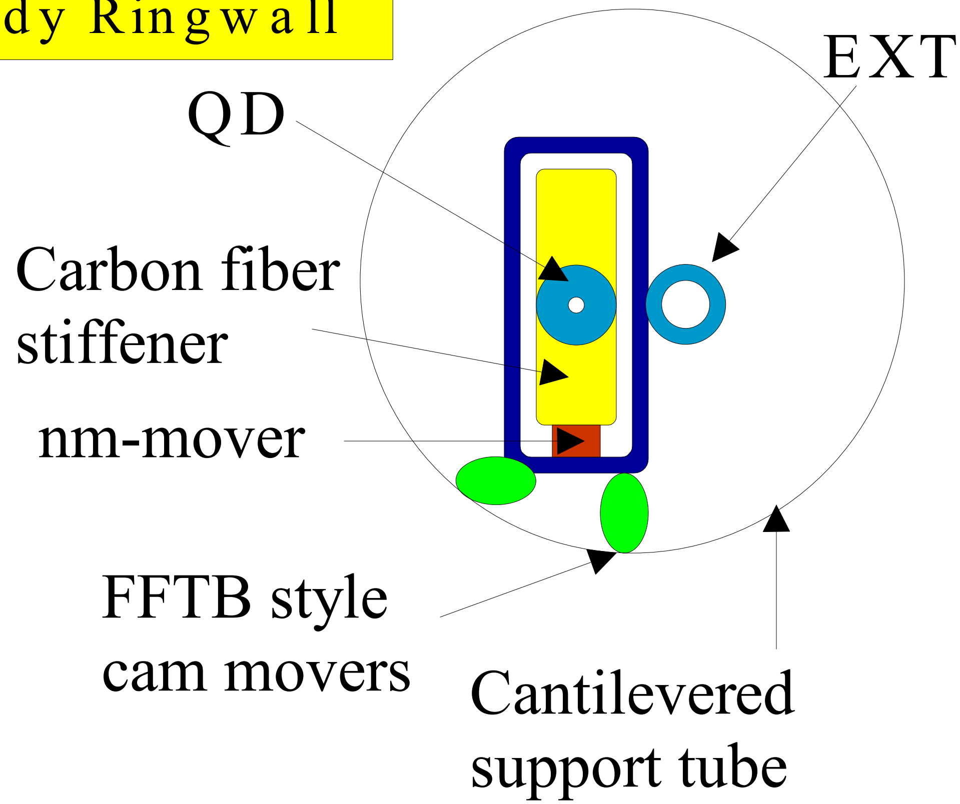
NLC Baseline: Permanent Magnet Quad

compact, stiff, connection free



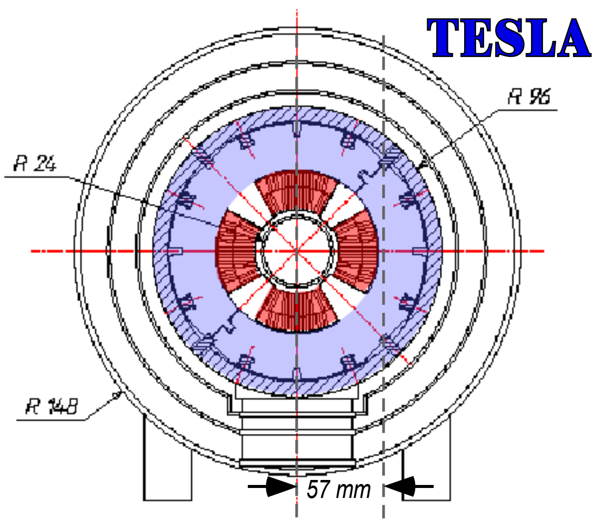
Andy Ringwall



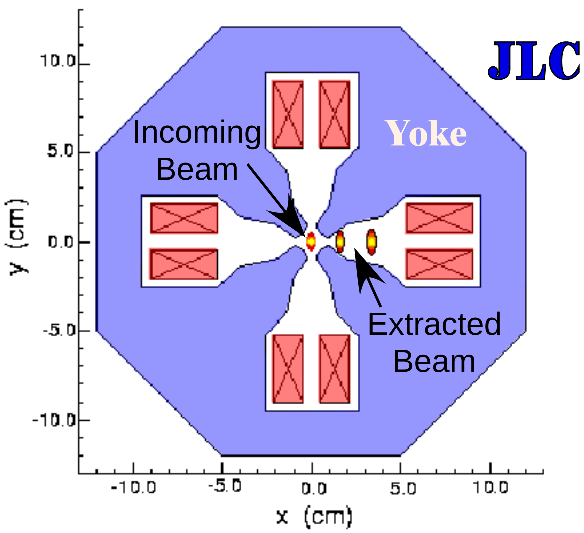
Magnet	Aperture	Gradient	Rmax	Z_ip	Length
QD0	1.0 cm	144 T/m	5.6cm	3.81 m	2.0m
QF1	1.0 cm	36.4 T/m	2.2cm	7.76 m	4.0 m

Knut Skarpaas

The TESLA and JLC Final Focus Quadrupole Concepts.



- Large aperture superconducting magnet (has both beams in the central region).
- Vertical extraction via electorstatic separator at 20 m and a shielded septum at 50 m.



- Iron magnet inside a superconducting compensator magnet (avoid saturation, buck out detector solenoid field).
- Extract the beam through coil pocket.

Key Point: NLC superconducting coil solution works if coil radius is kept small.

Get the conductor close to the beam...

- For given gradient, G, a smaller R_{coil} means required field strength is smaller ($B_{coil} = G \cdot R_{coil}$).
- A lower field strength means less conductor is needed; so the coil can be thinner (outer diameter minimized).
- Also the quadrupole moment is smaller and field falls of faster outside the coil (passing beam on to absorber).
- Both the coil self forces and the force due to interaction with detector solenoid are smaller (solenoid $B_r \propto R$).

Magnet Technology Choices

Permanent Magnets (NLC baseline)

- Compact, stiff, few external connections, no fringe field to affect extracted beam
- Adjustment more difficult

Superconducting (TESLA)

- Adjustable, big bore
- Massive and not stiff, would require windings to eliminate fringe field affecting extraction line if that is an issue

Iron (JLC)

- Adjustable, familiar
- Massive, shielded from solenoid, extraction in coil pocket seems daring

Detector Solenoid Field Effects on FD

- Detector size and field limits magnet technology choices
- Solenoid field effects:
  - Steel pole magnets
    - Saturates steel pole magnets; requires a flux excluder
    - Saturates steel shielding
  - Permanent magnets (PM)
    - Axial field rotates magnetization vector reducing strength; dependent on PM anisotropy energy
    - Radial field contributes to demagnetizing force on PM
  - Superconducting magnets (SC)
    - Reduces achievable critical current in SC wire
    - Develops large forces in SC coil

Superconducting Magnets for the HERA Luminosity Upgrade.

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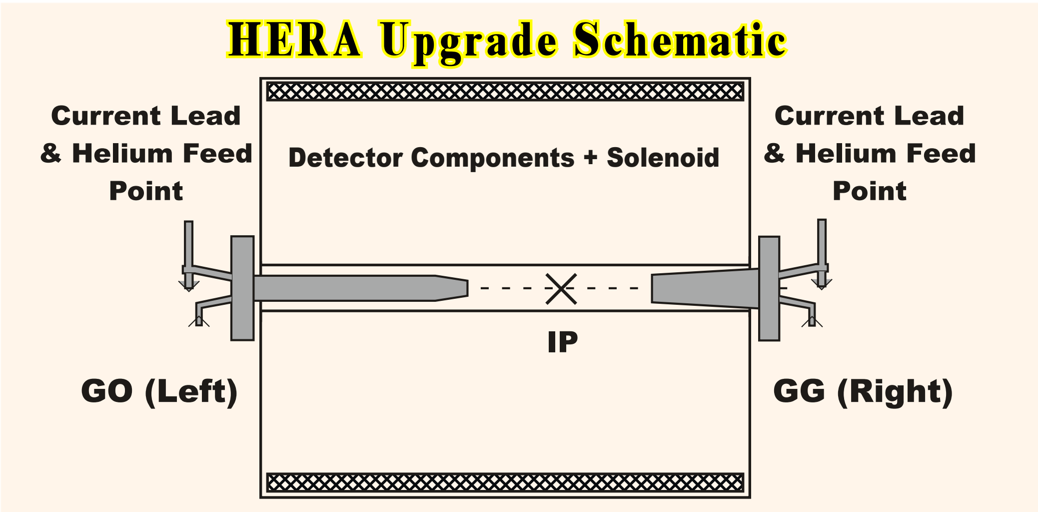

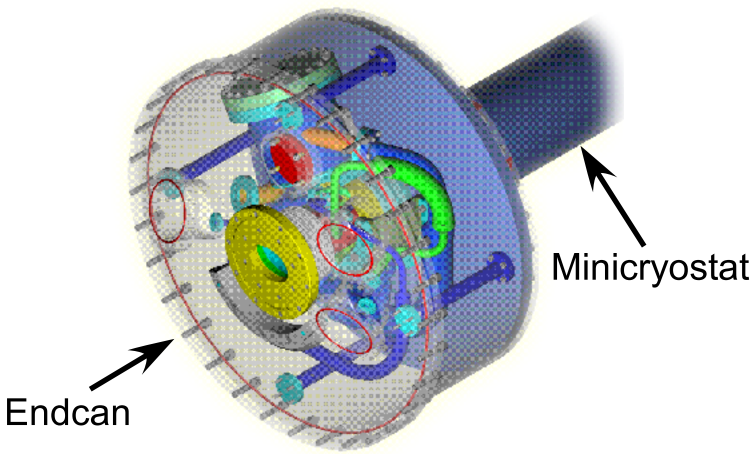

- Superconducting magnets installed into existing ZEUS and H1 detectors (solenoid, so no iron yoke).
- Coils for separating beams and reducing e-ring β^* (dipole, quad, skew-quad, skew-dipole & sextupole).
- Given extremely tight radial budget for cryostat.
- Met demanding field harmonic requirements.
- Developed technology, now use in BEPC-II Upgrade and possibly SLAC PEP-II B-Factory Upgrade.

Superconducting Magnets for the HERA Luminosity Upgrade.

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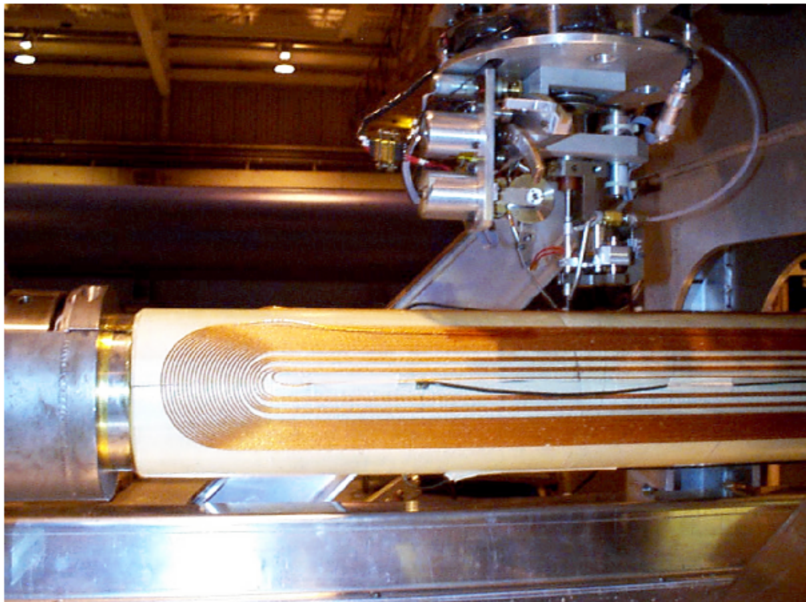
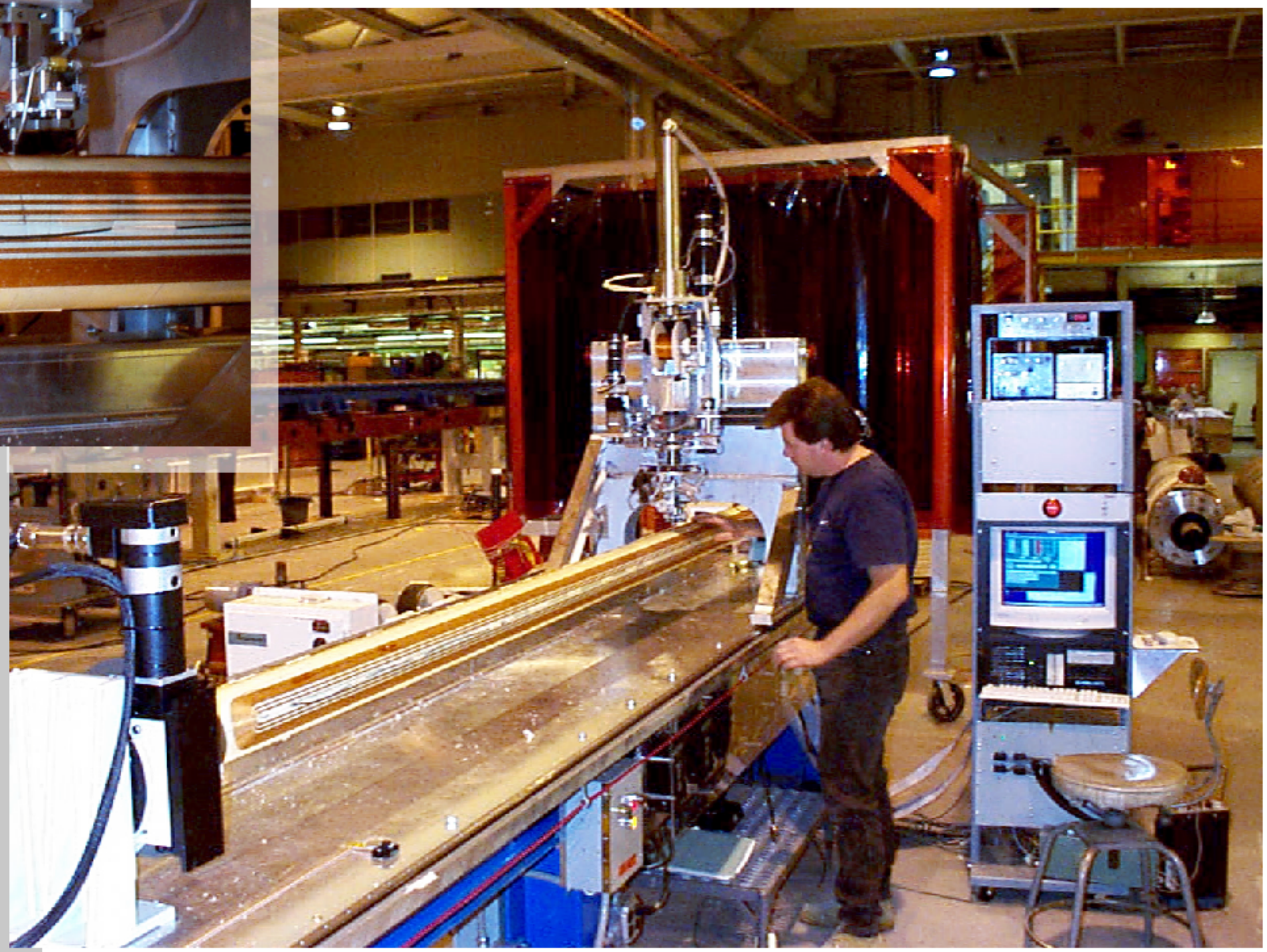
File used for field harmonics gives winding machine the path in space for the conductor.





Insulated conductor with b-stage epoxy coating is payed out under hollow stylus. Ultrasonic heating and rapid cooling leaves conductor bonded to substrate. Typically a coil goes next to magnetic measurements.

Superconducting Magnets for the HERA Luminosity Upgrade.

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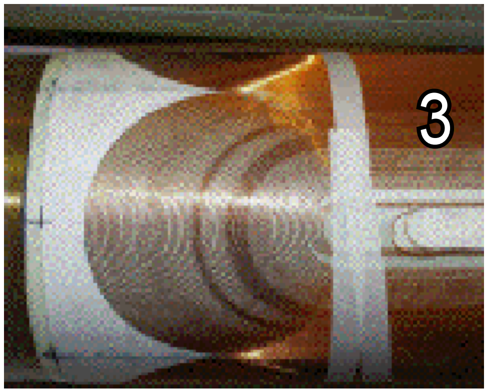
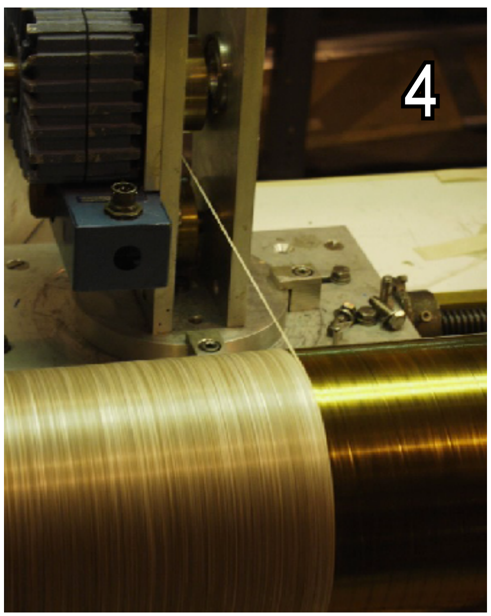




1) Create winding file and verify desired harmonics (*coilgen*, *coilfield*).

2) Winding machine lays pattern.

3) Check warm harmonics (if desired).

4) G10, epoxy and fiber glass wrap.

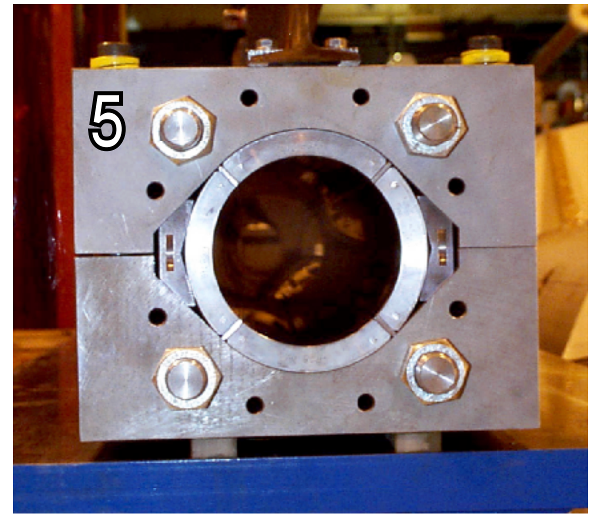
5) Cure with fixture (round surface).

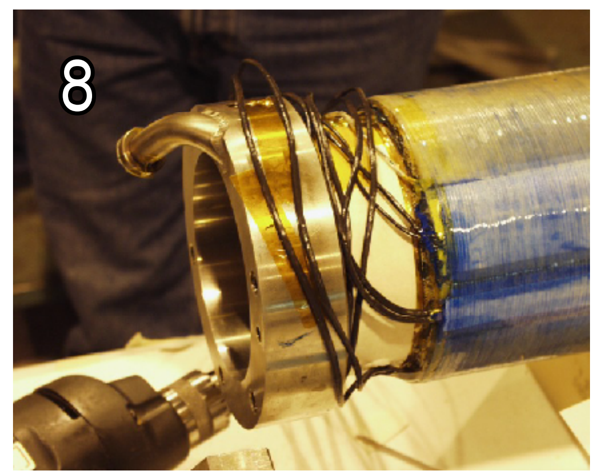
6) If not last layer, correct harmonics.

7) Repeat above with next coil type.

8) Test cold in vertical dewar (measure harmonics, quench test etc.).

9) Build up minicryostat structure.





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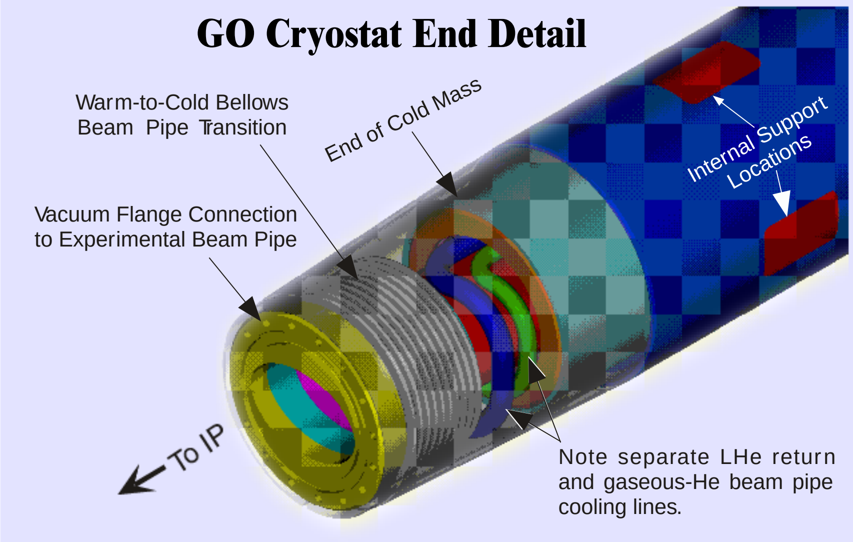
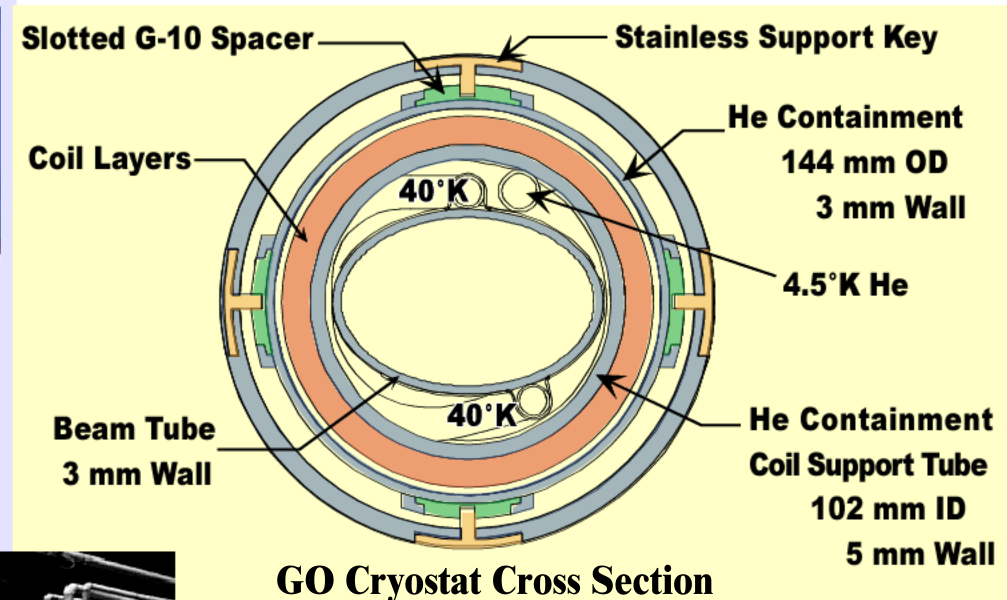
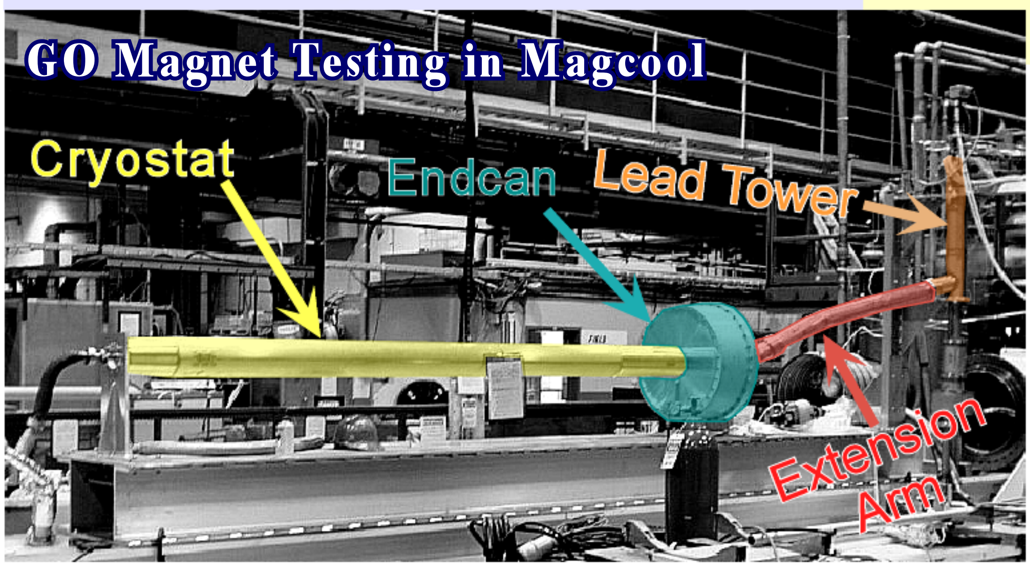


GO Cryostat End Detail



GO Cryostat Cross Section



GO Magnet Testing in Magcool

- Fiberglass prestress for each coil layer (note thick inner support tube).
- LHe flows between coil and the outer He containment (note "warm" beam tube).
- Key in G10 slots pass force from cold mass to the warm outer cryostat wall.
- Test GO & GG horizontal in BNL Magcool.

Next Step: BEPC-II magnet coils to be wound in double layers*.

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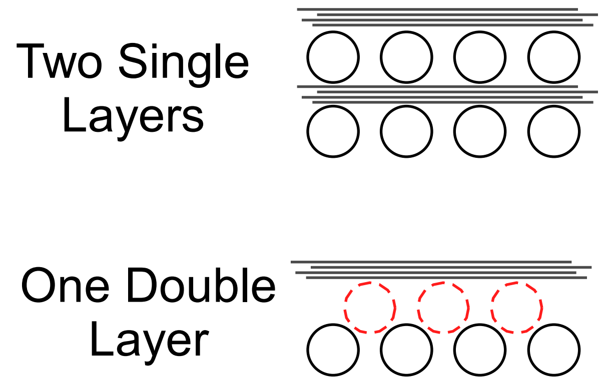
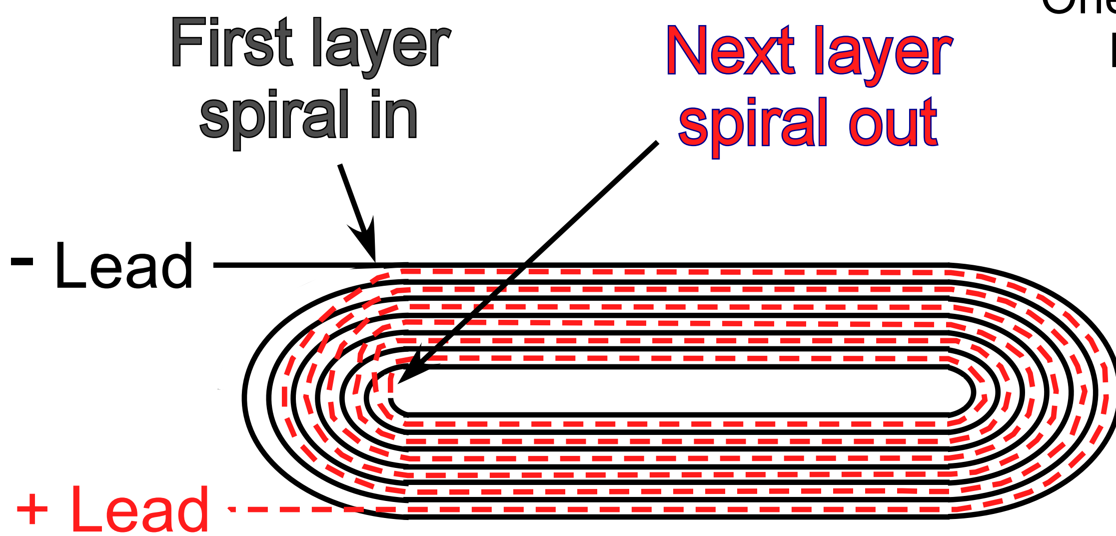
- Double layer winding moves leads from pole region to the midplane.
- Fewer wrapping and curing steps.





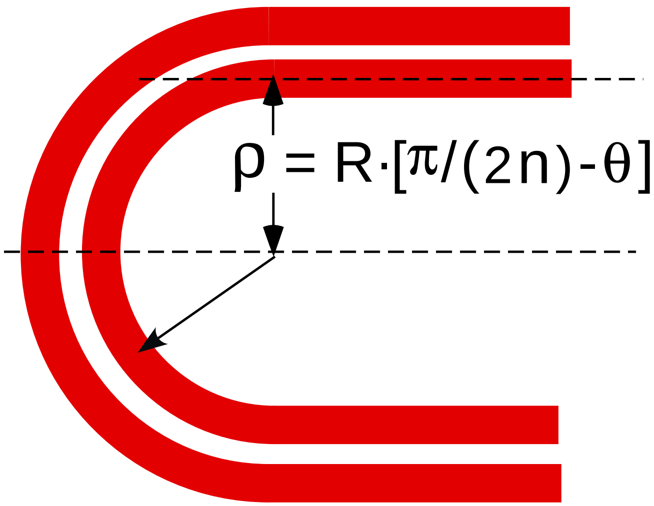
Then continue winding the next subcoil

*RHIC corrector flat patterns were routinely wound in double layers.

NLC Quad Strengths and Dimensions

Magnet	Radial Aperture	Gradient (500 GeV) (1TeV)	Rmax (500 GeV) (1TeV)	Z_ip	Length
QD0	1.0 cm	144 T/m 288 T/m	4.6 cm+3/8”=5.6cm XXXXX	3.81 m	2.0m
QF1	1.0 cm	36.4 T/m 72.8 T/m	1.2cm+3/8”=2.2cm 1.7cm+3/8”=2.7cm	7.76 m	4.0 m

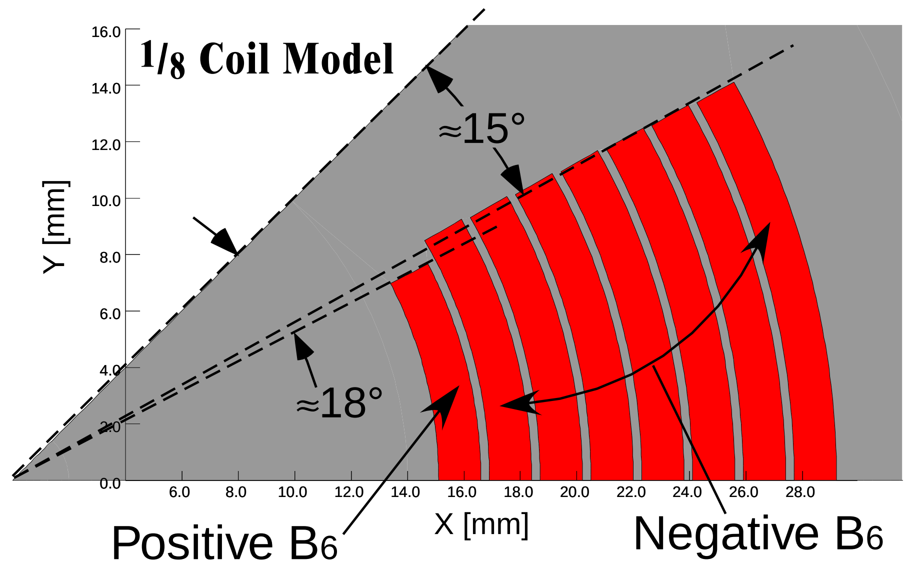
Coil Design Principles: How tight is the cable bend at the pole?



For a quadrupole coil n=2.

Imagine laying a winding layer out flat...

Then it becomes obvious that the bend radius is a function both of coil layer radius and the angle between the last winding and the pole.



15 mm @ 18°
or 17 mm @ 15°

give $\rho \approx 4.5$ mm
for the coil shown

HERA upgrade 6-around-1 cable has ≈ 1 mm OD.

Roy Rogers' "the thinner you slice it, the more the beef" does not work here.

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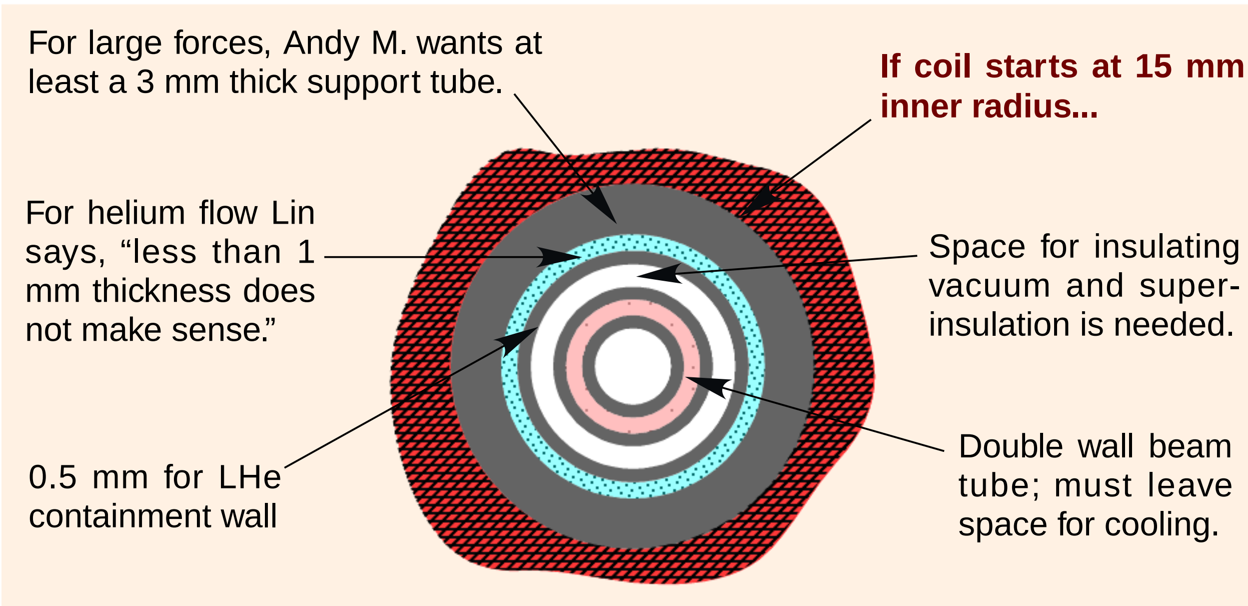

With 80°K beam tube and LHe cooling flow inside coil support tube, even a 5 mm radial budget is not enough. How can we do better?

Answer: Move some of this structure out to larger radius and start winding coil with a smaller diameter conductor but tighter in.

NLC QD0 Concept: Independent quadrupole coils & warm beam tube.

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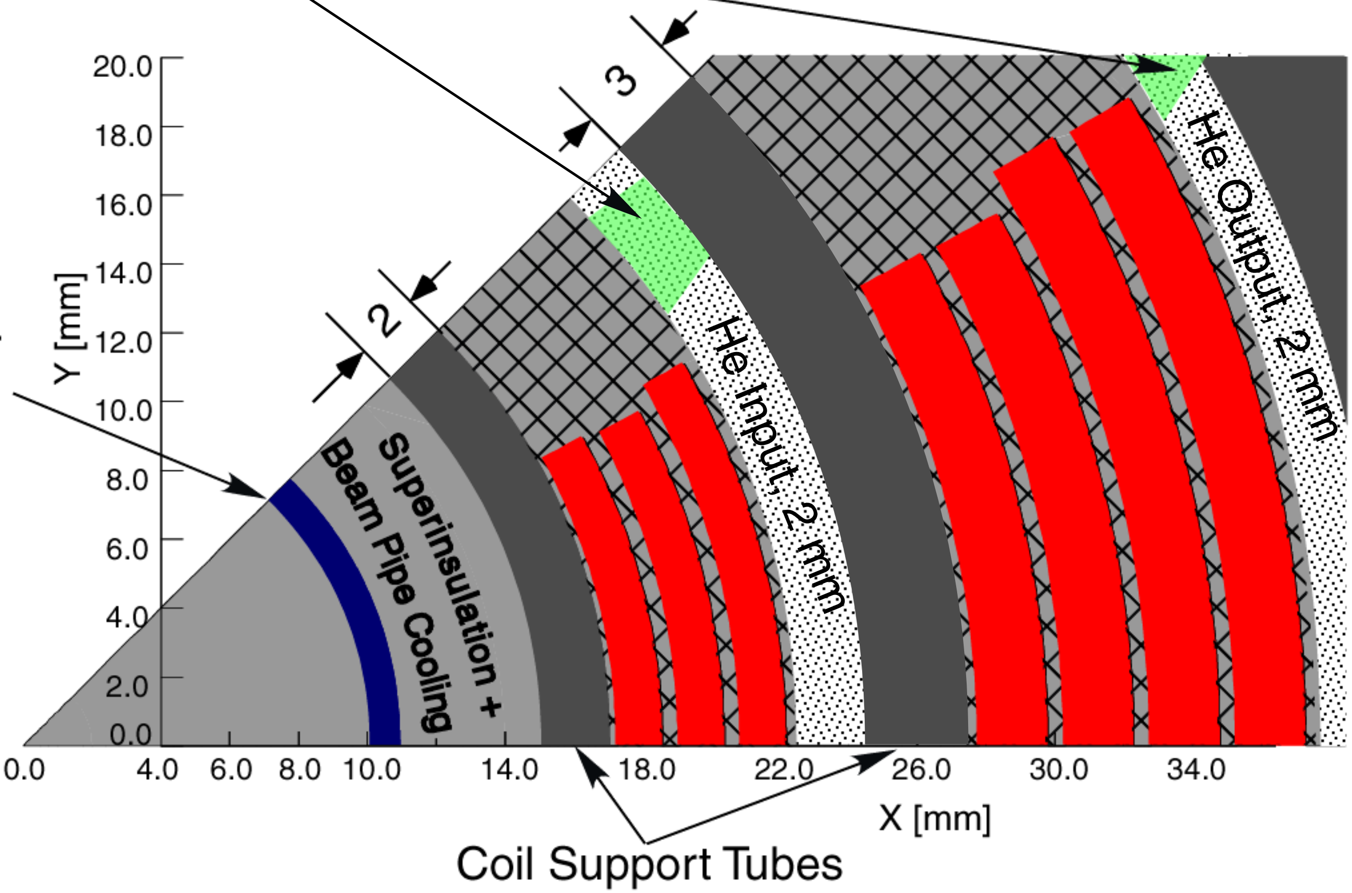
Tight inner bends done with 0.648 mm RHIC strand. For outer coils 1 mm DESY/RHIC 6-around-1 cable is ok.

Bumpers could be used to couple structural elements

Try to limit the inner structure to keep inner coil radius small.

Beam pipe inner radius is 10 mm

Inner and outer coils each give about half total 144 T/m gradient.



QD0 Design: Coil Self Force Estimate (prestress & support tube thickness).

Force / unit length = $\int J \times B \, ds$

Support tube takes up coil prestress.

Note: 1/8 model has net downward vertical force that is cancelled by bottom half coil.

Support Tube:
let t = 2 mm

$P = F/A = F/(2RL)$

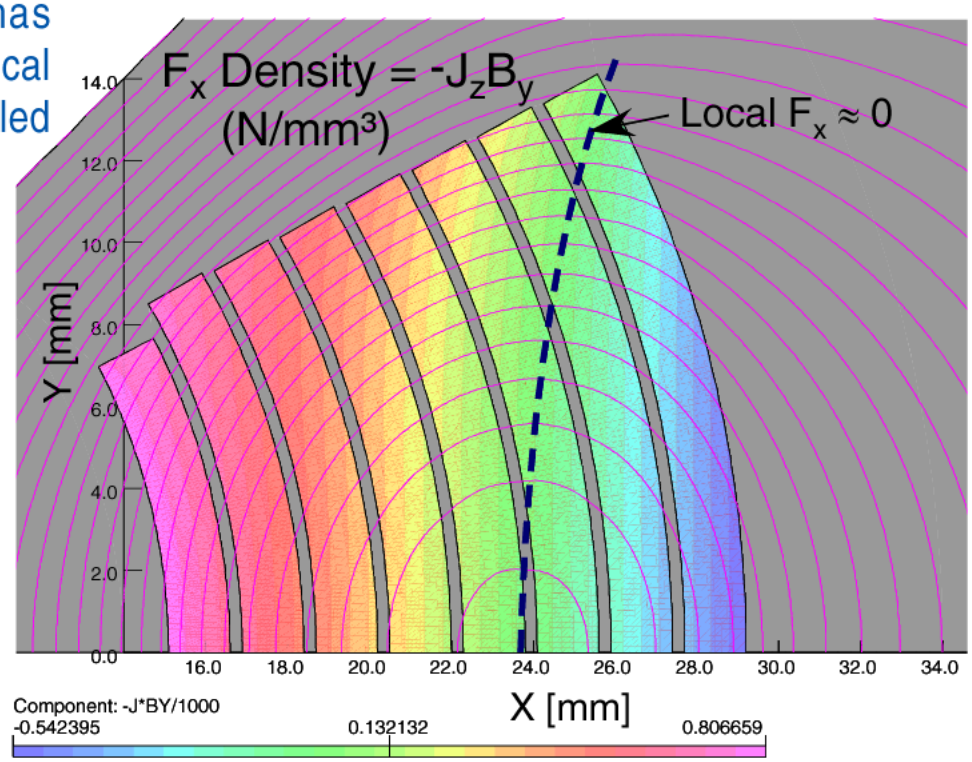
$\text{HoopStress} = P \cdot (R/t)$

$= (F/L) \cdot 1/(2t)$

$= 48.8/4 = 12 \text{ N/mm}^2$

$= 12 \text{ MPa}$

$= 12 \cdot 0.145 = 1.7 \text{ kpsi}$



For 1/8 model

Layer #	Net F_x (N/mm)
1-2	8.2
3-4	8.3
5-6	7.0
7-8	5.4
9-10	3.3
11-12	0.7
13-14	-2.4
15-16	-6.1
Total =	24.4

Final design has two support tubes, each of which takes up only part of the total force.

Estimating the fringe field from NLC final focus quadrupoles.

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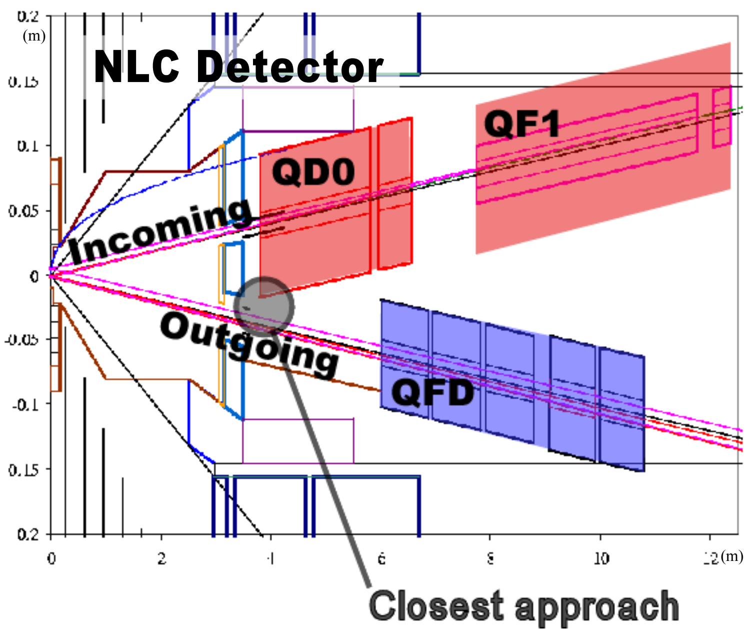
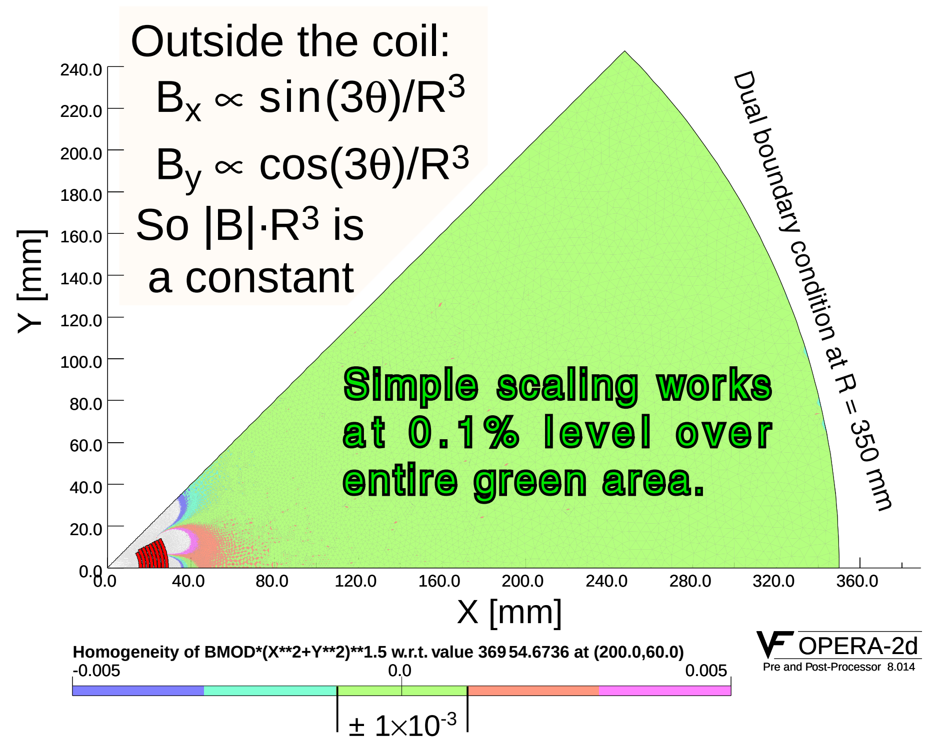
Outside the coil B-field is quite predicable and rapidly becomes small in magnitude.





Expect only a negligible effect on outgoing beam.

Cooling scheme proposed for NLC QD0 with 80°K beam pipe.

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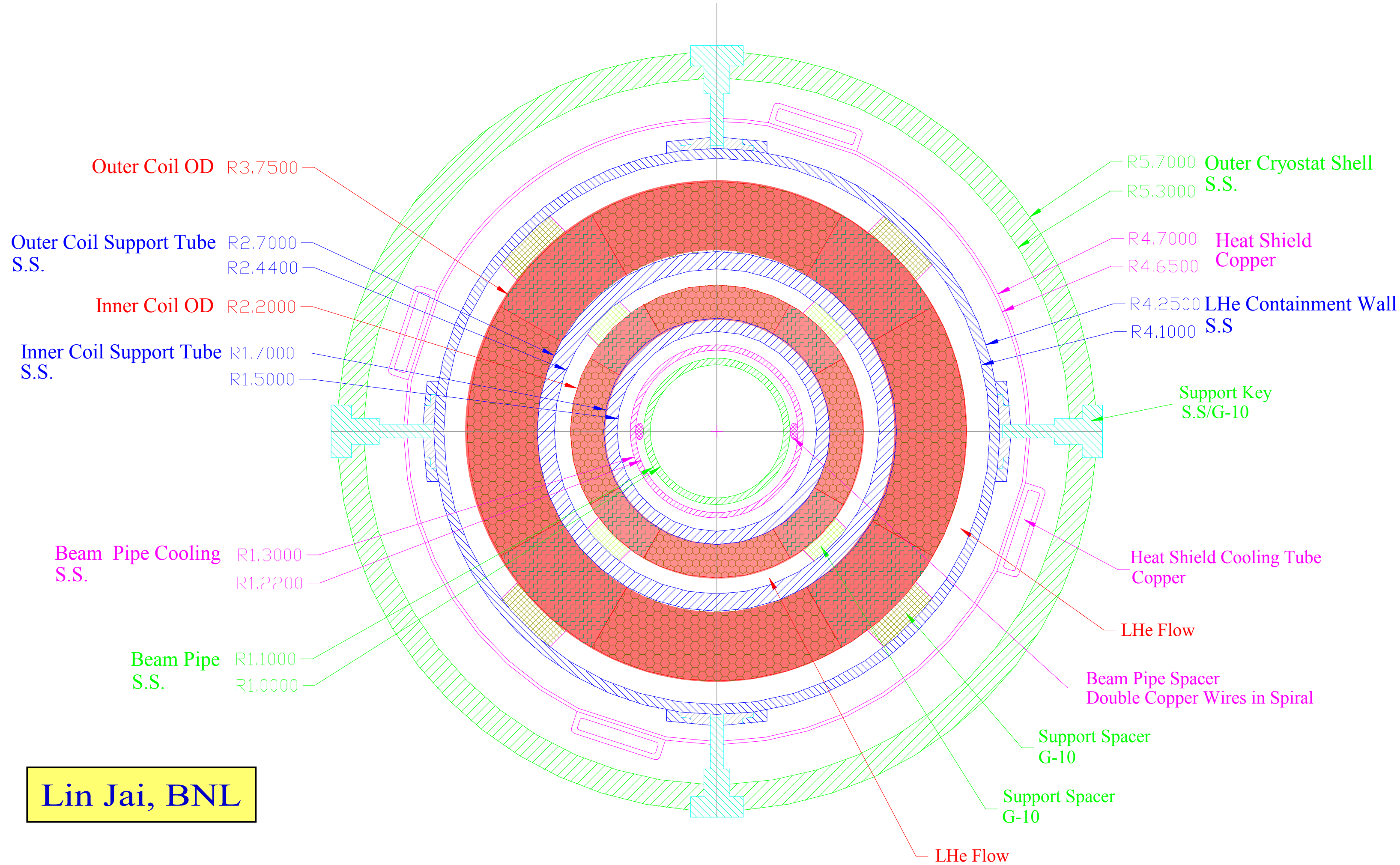

Lin Jai, BNL

NLC physicist feedback during December 2001 meeting at SLAC.

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During mid–December visit to SLAC, presented design that met **144 T/m gradient** goal, fit inside **R = 5.7 cm** space constraint, did **not** require **"magic materials"** and could be done with **existing technology** developed for the HERA upgrade project.

... maybe not wild enough!

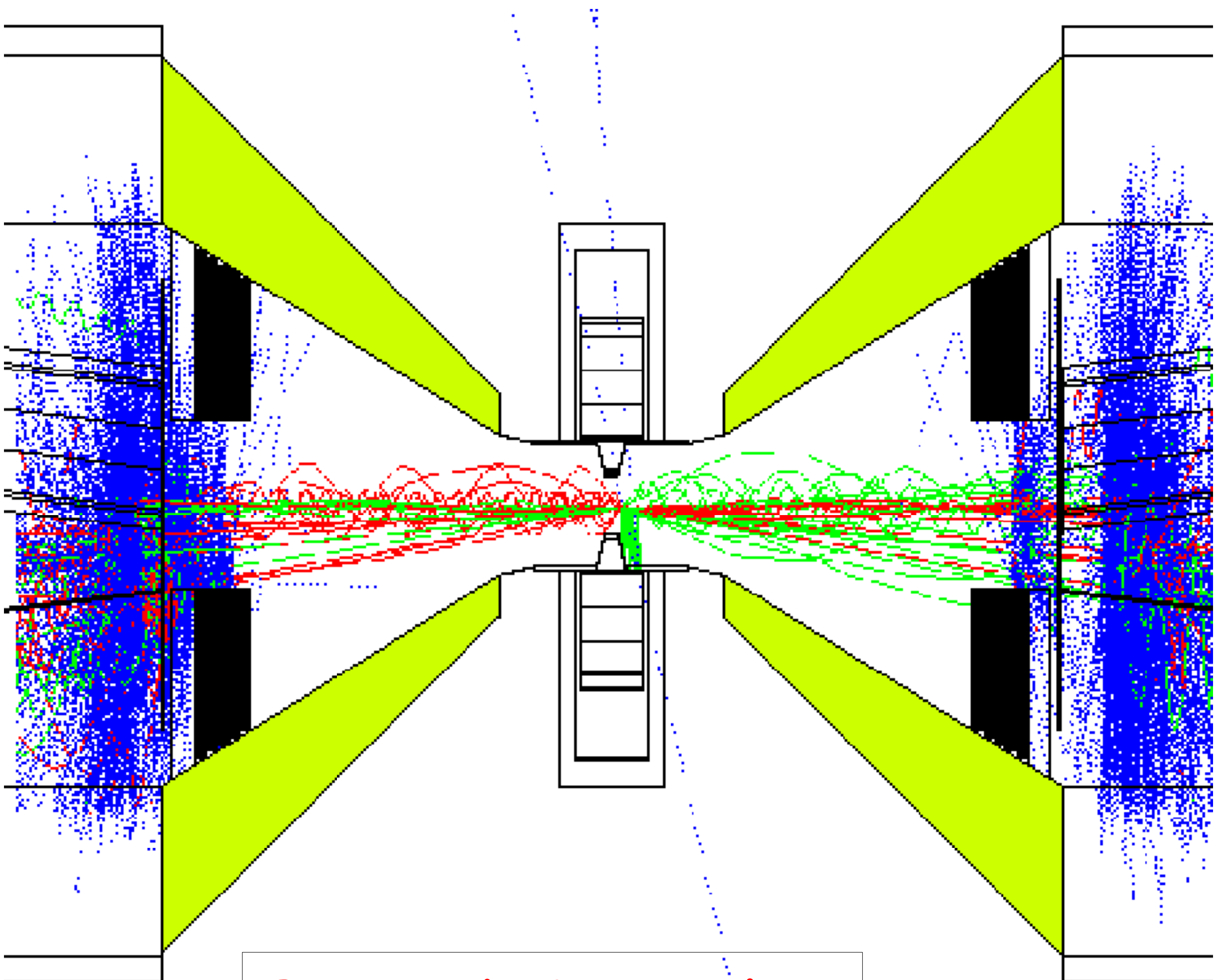
- **Why 80°K beam pipe? (coil support tube used as 4°K beam pipe)**

In spite of the 110 μm bunch length, NLC has low rep rate and beam heating should not be an issue. Also NLC crossing angle and detector solenoid field means very little energy deposition in QD0 (Nan Phinney and others).

- **What about adding a sextupole coil?**

Can have better optics solution and more effective use of sextupole strength with sextupole coils closer to IP.

e+,e- pairs from beams. γ interactions



B_{SOL}, L*,& Masks

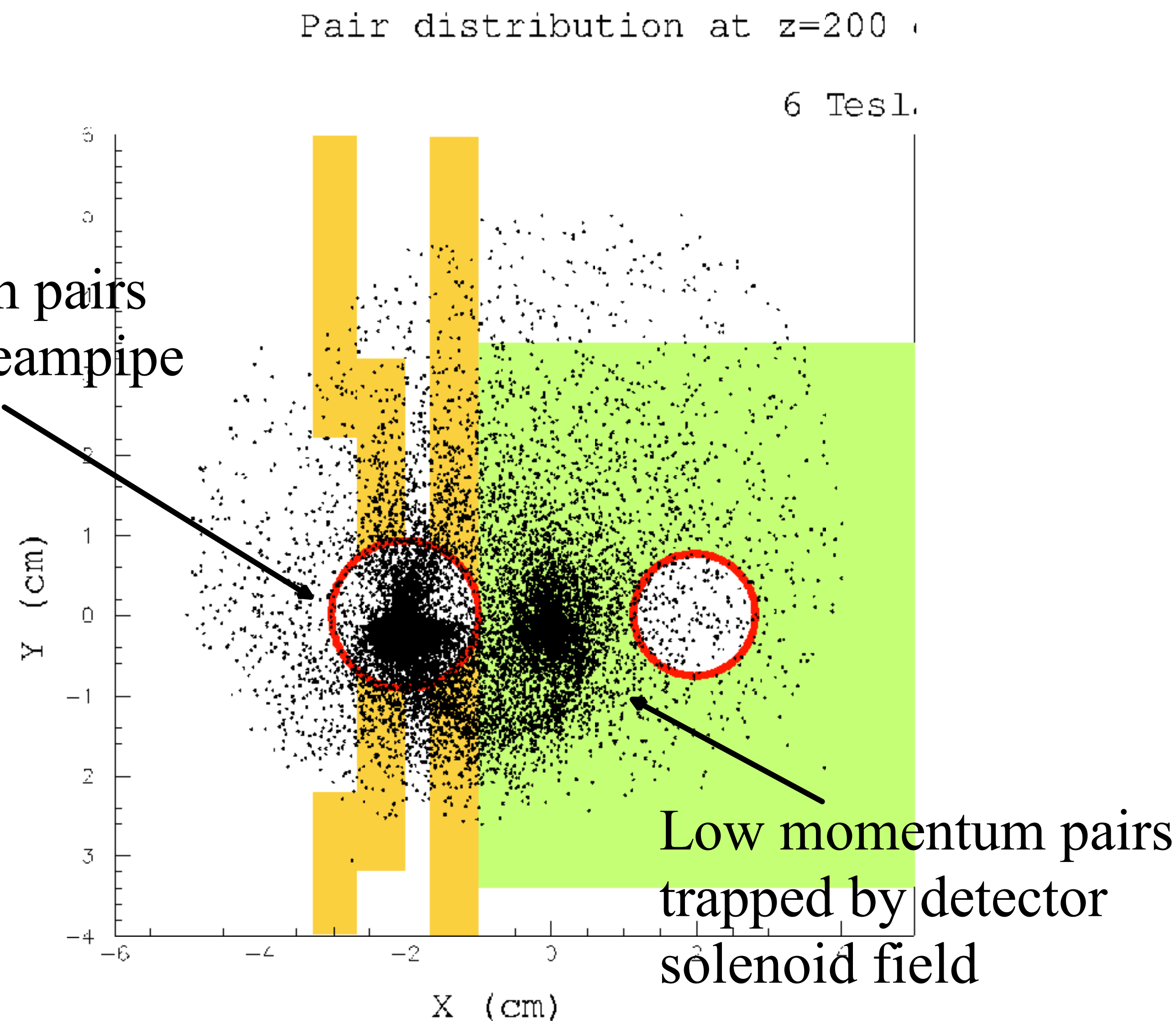
pairs scales w/ Luminosity

1-2x10⁹/sec

0.85 mW per side

Luminosity Monitor & Pair Monitor will Shield QD

e,γ,n secondaries made when pairs hit high Z surface of LUM or Q1



QD0 Cross Section with 4°K Beam Tube and Sextupole Winding.

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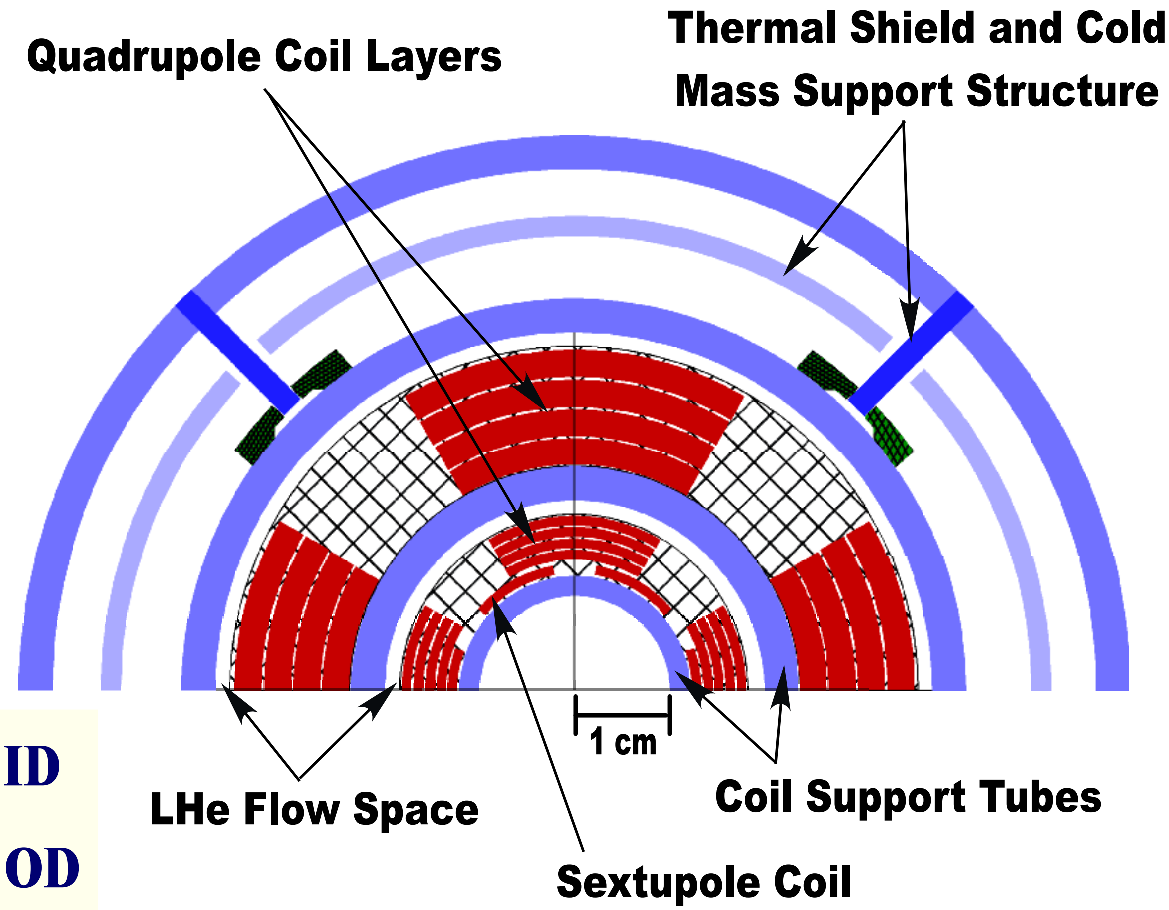
QDO Coil Parameters

Sextupole	1300 T/m²
Inner Quad	51 T/m
Outer Quad	93 T/m
Total Quad	144 T/m

Inner Beam Tube	20 mm ID
Outer Cryostat Tube	114 mm OD



Assume inner support tube is copper coated and also serves for beam vacuum.

Superconducting Magnets for NLC Final Focus – Future Work.

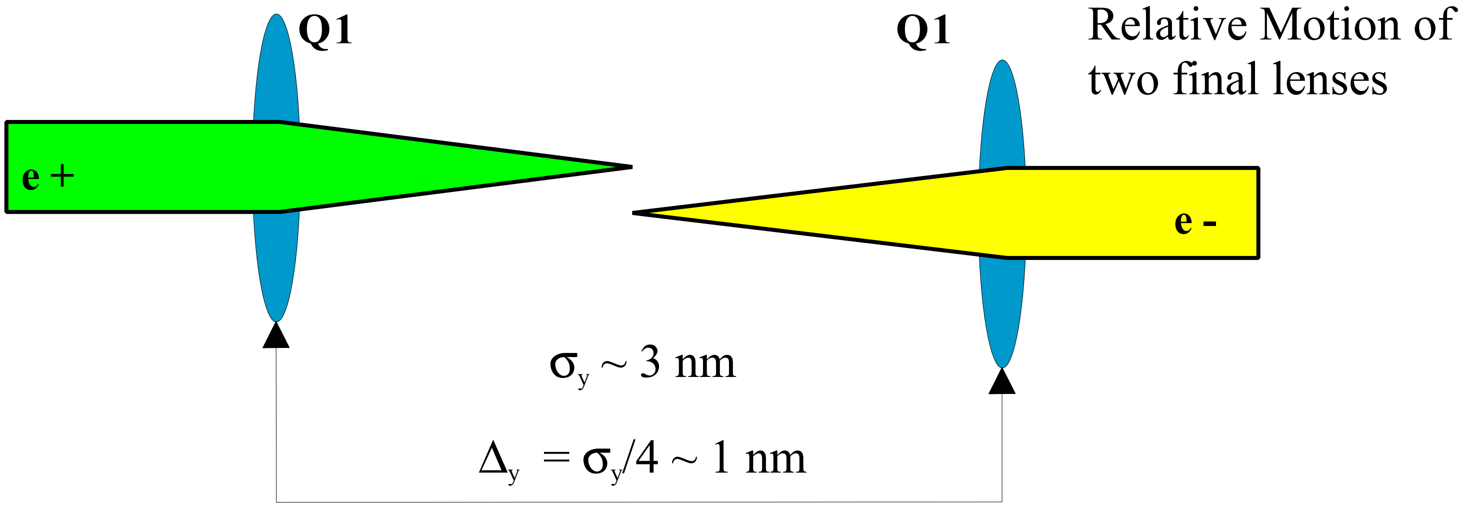
- **Make a small diameter short test coil (winding parameters, LDRD).**

- **Study is needed to verify aperture and external field requirements (esp. energy deposition issues).**

- **Investigate vibration mitigation issues (possible tests at SLAC).**

Andrei Seryi and John Weisend, SLAC

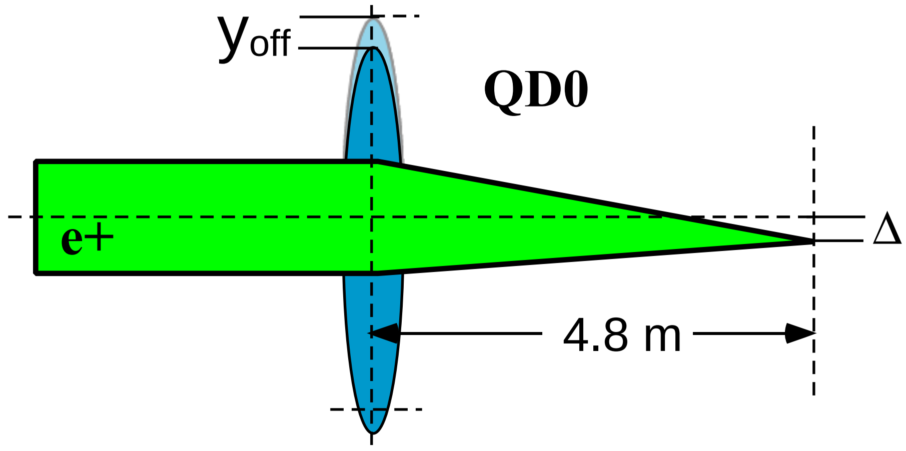
Colliding Small Beam Spots at the IP



Control position & motion of final quads and/or position of the beam to achieve/maintain collisions

- **Get a seismically quiet site**
- **Don’t screw it up: Pumps, compressors, fluids**
- **Good magnet and detector engineering: Light, stiff Q1 in a rigid detector**
- **Tie to “bedrock”: get lenses outside detector as soon as possible**

NLC Beam Delivery System: Quadrupole Offset Sensitivity.



Let y_{off} = 1 nm, then ΔB = 1.44e-7 T

$$\theta = \frac{2 \cdot 1.44\text{e-}7}{834} = 0.34\text{e-}9 \text{ radians}$$

$$\theta \cdot L = 4.8 \cdot 3.4\text{e-}10 = 1.6\text{e-}9 \text{ m}$$

P = 250 GeV/c
$B\rho$ = 834 T·m
G^{QD0} = 144 T/m
σ_y^{QD0} = 0.11 mm
$\Delta\theta_y^{QD0}$ = 0.74 nr
σ_y^{IP} = 3 nm
L^* = 3.8 m
L_m^{QD0} = 2 m

With this simple model vertical quadrupole movement of 10^{-5} σ causes the beam to move by ≈ ½σ at the IP.

NLC Final Focus Magnet Summary.

February 15, 2002

Dear Brett,

We continue to be very interested in pursuing the possibility of using a compact high gradient superconductiong quadrupole in the final magnet doublet at the interaction point. The design work you have done since our first contact at Snowmass and that you presented to us this past December looks very promising. We look forward to continuing our discussions on the detailed requirements of these magnets, their operating environment and of the tests that would be required to provide confidence in their design.

Tom Markiewicz, Beam Delivery System Manager