DR Magnets & Power Supply System

ILC DR Technical Baseline Review
Frascati, July 8, 2011

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DTC Magnet Counts

DTC Magnet Summary (single ring) from D. Rubin

Element	Length[m]	Strength	Number
Arc Dipoles	3	2.28 kG	150
Circumference changing chicane dipoles	1	2.68 kG	28
Other dipoles	2	< 2.28 kG	4
Arc Quadrupoles	0.6	$< 0.6\ m^{-2}$	450
Quadrupoles in dispersion suppressor and straights	0.3	$< 0.55\ m^{-2}$	211
Sextupoles	0.3	$< 4.34\ m^{-3}$	600
Wigglers	1.92	54	54

Estimated Physical Magnet Count

- Comparison with RDR
- Apply certain assumptions
  - **2 sextupoles on either side of single quad can ultimately be replaced by a single magnet**
  - **Adjacent quadrupoles combined into single magnets**

Magnet Counts Individually Powered Magnets	**RDR** (single ring)	**DTC** (single ring)
DC Bus-Based		
Quadrupoles	747	657
Sextupoles	504	452
Skew Quads	240	240
H Correctors	150	150
V Correctors	150	150
Total DC Bus-based	**1791**	**1649**
Individual AC-to-DC		
Wigglers	80	54
Dipole Strings		
6m Arc Dipoles	114	
3m Arc Dipoles	12	150
1m Chicane Dipoles		28
2m Dipoles		4

Similar Counts

Magnet Comments

- Normal conducting magnets
  - **Quadrupoles**
    - RDR – had high and low current quadrupoles
      - 551 **low** current (V1) quads (74%)
      - 196 **high** current (V2,3,4) quads (26%)
    - DTC quadrupoles can be matched to same physical families
      - 583 **high** current (V2,3,4) quads (89%)
      - 74 **low** current (V1) quads (11%)
    - High/Low Cost Ratio (magnets-only): ~1.5
  - **Dipoles:**
    - Rough scaling is that expect DTC 3m arc dipole to be comparable in cost to the RDR 6m dipole
    - Additional dipole styles
    - Net cost increase
  - **Sextupoles: Need to be re-scaled (~5x K2 ratio), more expensive**
  - **Correctors: Assume roughly same distribution and cost**
- On net, expect NC magnet cost to increase

Wigglers

- Wigglers: DTC parameters are (intentionally) closely matched to the *ILC "Optimized" Wiggler* design.
- Optimized wiggler expected to cost ~75% of the design costed for the RDR
  ⇨ Wiggler cost ratio per ring: $\sim 0.75 \times 54/80 = 51\%$

ILC Optimized Wiggler

- **12 poles**
- **Period = 32 cm**
- **Length = 1.68 m**
- **$B_{y,peak}$ = 1.95 T**
- **Gap = 86 mm**
- **Width = 238 mm**
- **I = 141 A**

Preliminary Estimate

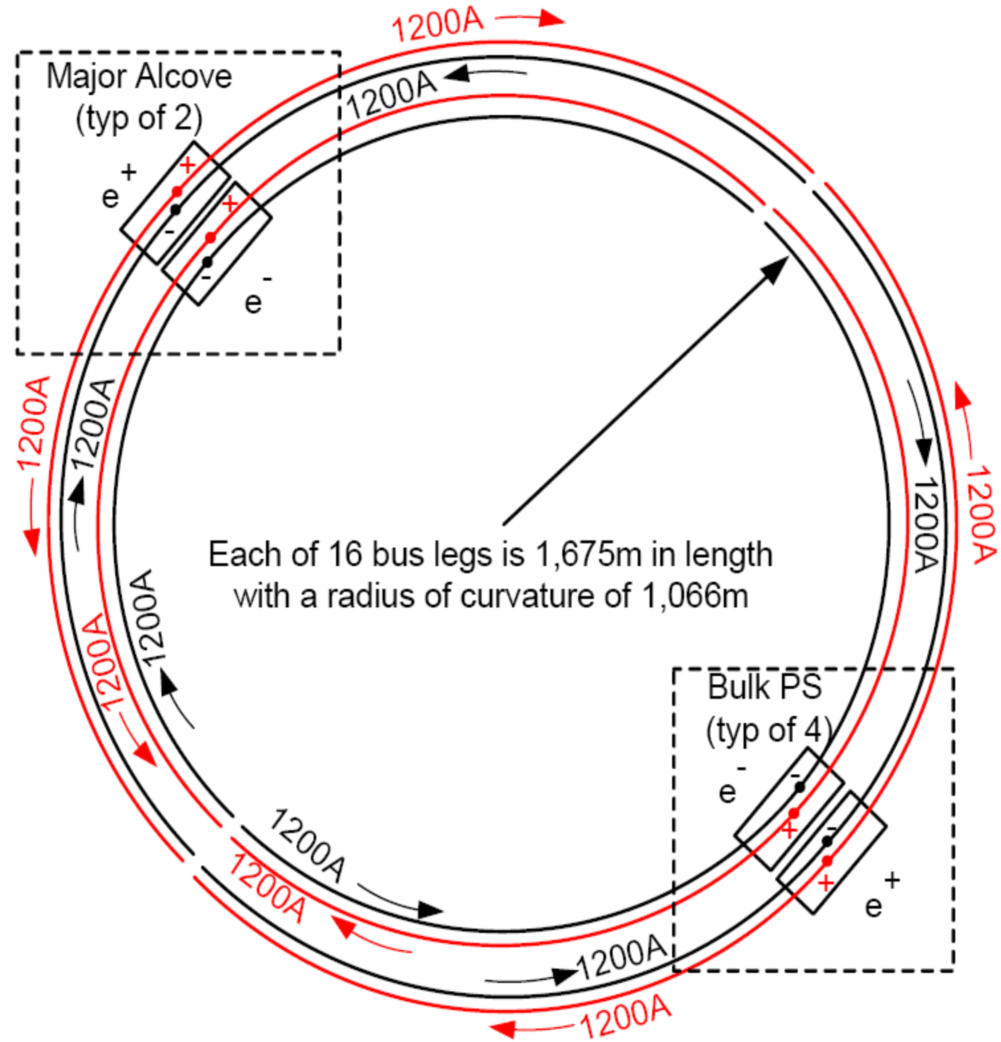
Power Supply System

- RDR used bulk supplies for dipoles and discrete supplies to individually power all other ring magnets
- Post-RDR estimates made for a *distributed power supply system* for individually controlled magnets
- DTC system assumed to utilize the distributed power supply system
- Assume 4 bulk dipole power supplies for DTC arcs
  - **Versus 6 in RDR**
  - **Add 1 bulk supply for chicane**
  - **Additional supplies for specialty dipoles**
- Pulsed element supplies unchanged from DCO4 configuration

Distributed Power Supply Concept

- 4 bulk supplies
  - **2 in each major alcove**
  - **Feed 8 buses (4 per ring)**
  - **Individual DC-to-DC converters for each magnet**
    - Water-cooled racks distributed around the ring
    - Magnets
      - Quadrupoles
      - Sextupoles
      - Correctors (dipole, skew quad, other)
  - **Distribute AC to local wiggler power supplies**
  - **Reduce heat load around tunnel due to cable losses to air to <50W/m**
- Main dipoles powered in 6 strings per ring
  - **6 dipole supplies per alcove**
- Injection/Extraction lines
  - **Same as for RDR**

Quadrupole, Sextupole & Corrector Bus



Sampling of Specifications

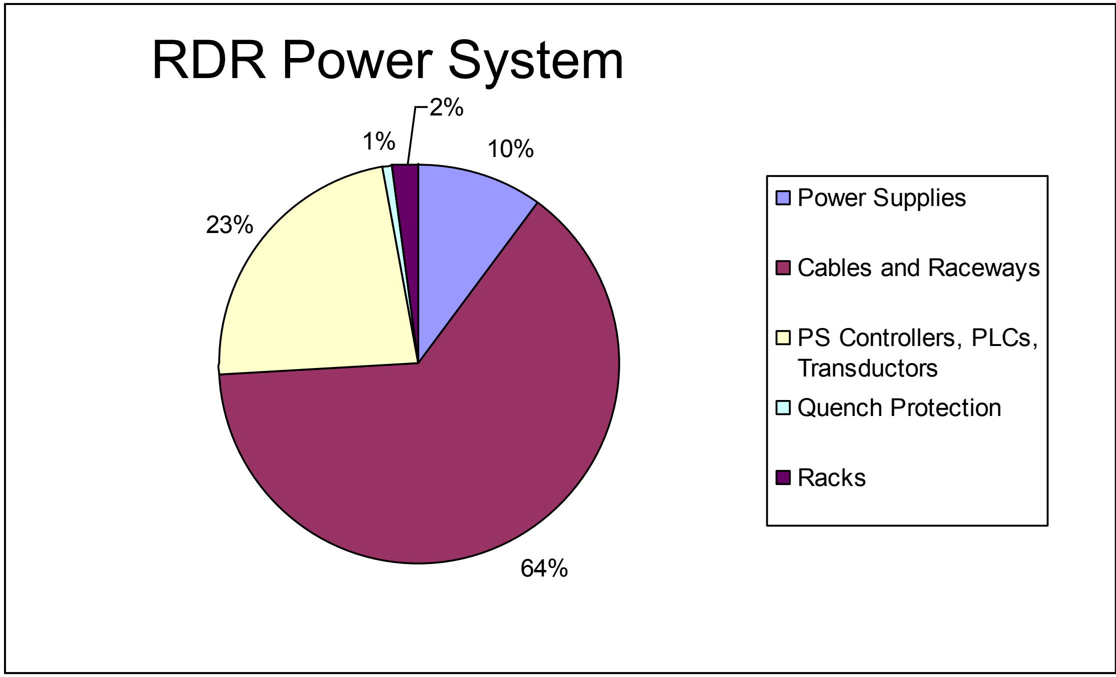
- Air heat load
  - **Solid conductor magnets (~100kW/ring)**
  - **Short cables between DC-to-DC converters and:**
    - Bus
    - Magnets

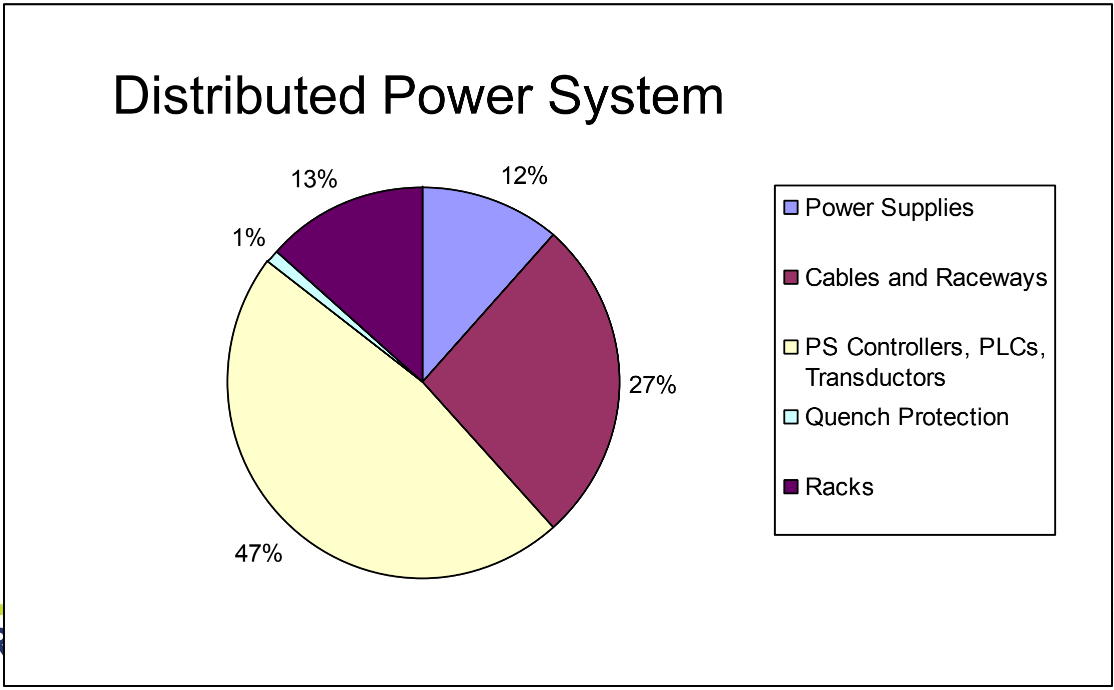
⇨ ~40W/m

Bulk Power Supplies (4 units)	
Output Power	120 kW
Output Voltage	50 VDC (voltage regulated)
Output Current	2400 A
Input	480 VAC, 3 phase
DC Bus	
Min/Max Voltage	40V/50V
Max Resistance	17 mOhm
Min Cross Section	5372 mm^2 Al
DC-to-DC Converter Cabling	
Max distance to magnet	7m
Max distance to bus	5m
Magnets	
Max Operating Voltage	30 V

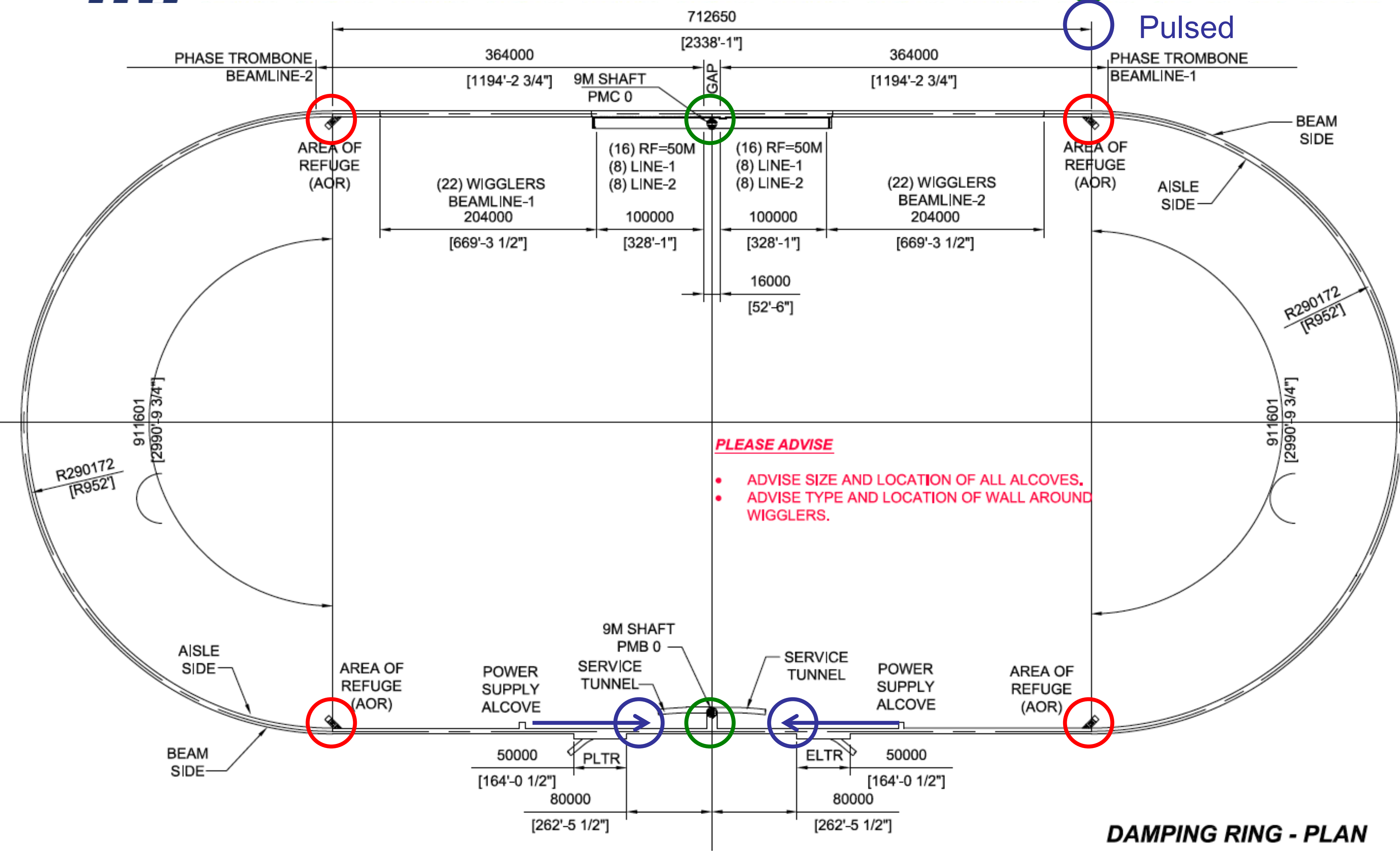
Cost Impact

- Cable costs greatly reduced!
- 35% cost savings relative to RDR
- Controls-related hardware now dominant cost
  - **Some obvious further work to reduce costs in this area**





PS Locations



Very Rough DC PS System Estimate

- Assume similar bulk/dipole PS specifications (needs validation)
- Assume similar bus specifications (typical magnet spec has changed so this needs validation)

Cost Estimate	RDR (2006 M$)	DTC (2006 M$)	% Change
Power Supplies	5.2	4.1	78%
Cables and Raceways	33.3	9.2	28%
PS Controllers, PLCs, Transductors	12.0	14.5	121%
Quench Protection	0.5	0.2	44%
Racks	1.0	4.4	424%
Total per Ring	**52.0**	**32.4**	62%

- NOTE: RDR ring cost would have been $34M

Preliminary Estimate

Supporting Slides

- Extra slides describing the “ILC optimized wiggler” concept follow

Optimized CESR-c Wiggler Design

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Outline

- Baseline Wiggler Configuration
  - **Basic Requirements**
  - **Comments on RDR Costing Exercise**
- Work Towards a Final Design
  - **Superferric Wiggler Physics Optimization**
    - Poles
    - Period
    - Gap
    - Width
    - Peak Field
  - **Engineering Issues and Optimization**
    - Expected Cost Impact
- Conclusion

Baseline Wiggler Configuration

- Basic Requirements
  - **Large Aperture**
    - Physical Acceptance for injected e+ beam
    - Improved thresholds for collective effects
      - Electron cloud
      - Resistive wall coupled bunch instability
  - **Dynamic Aperture**
    - Field quality
    - Wiggler nonlinearities

Wiggler Comparison

	TESLA	CESR-c	Modified CESR-c
Period	400 mm	400 mm	400 mm
$B_{y,peak}$	1.67 T	2.1 T	**1.67 T**
Gap	25 mm	76 mm	76 mm
Width	60 mm	238 mm	238 mm
Poles	14	8	**14**
Periods	7	4	**7**
Length	2.5 m	1.3 m	2.5 m

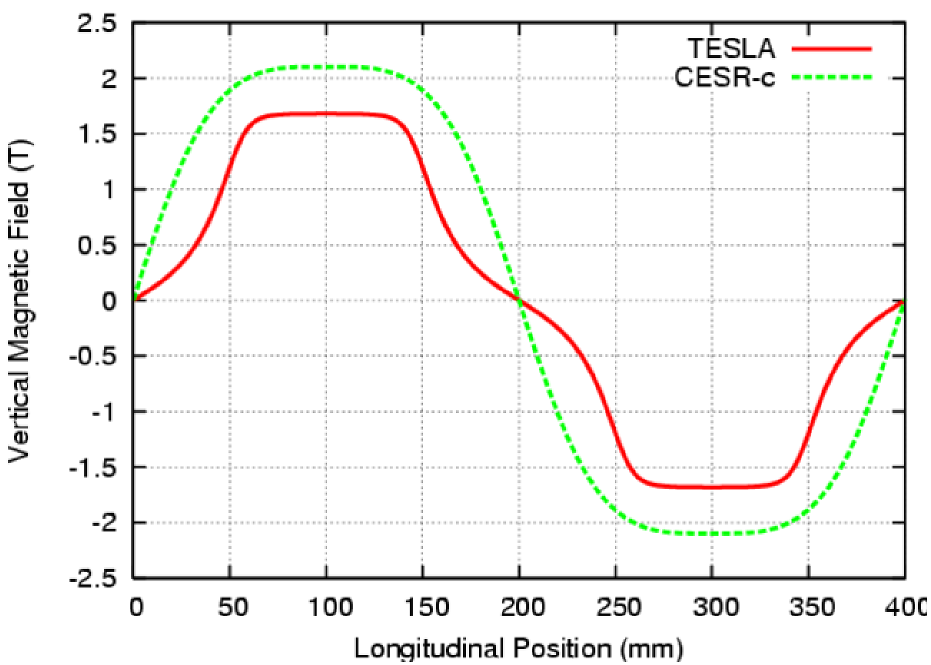
Wiggler Comparison

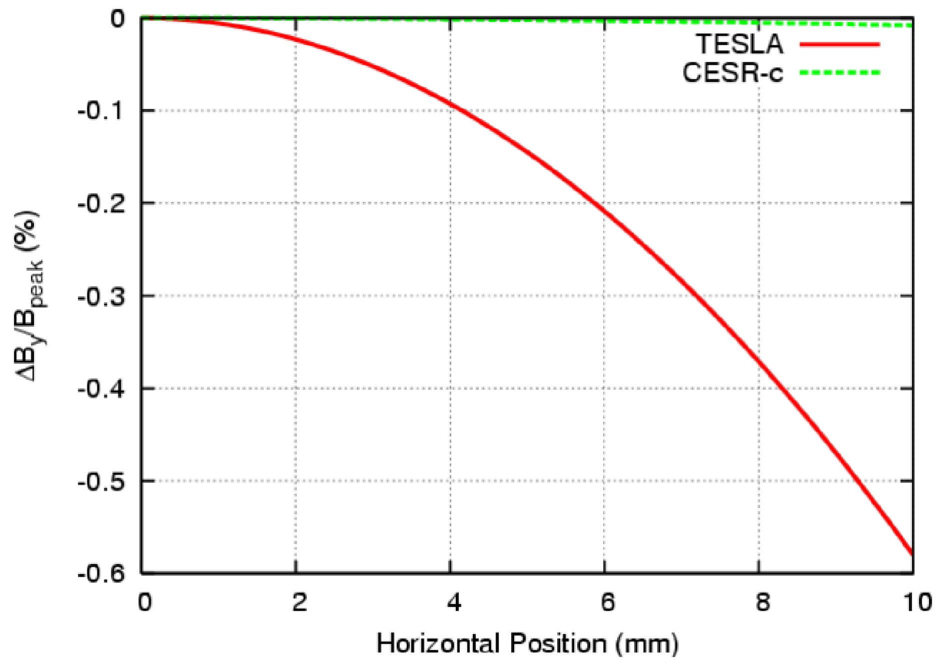
TESLA Wiggler

Hybrid permanent magnet
NdFeB with iron poles
$\Delta B_y/B_{peak}$ (x=10mm) = $5.7*10^{-3}$

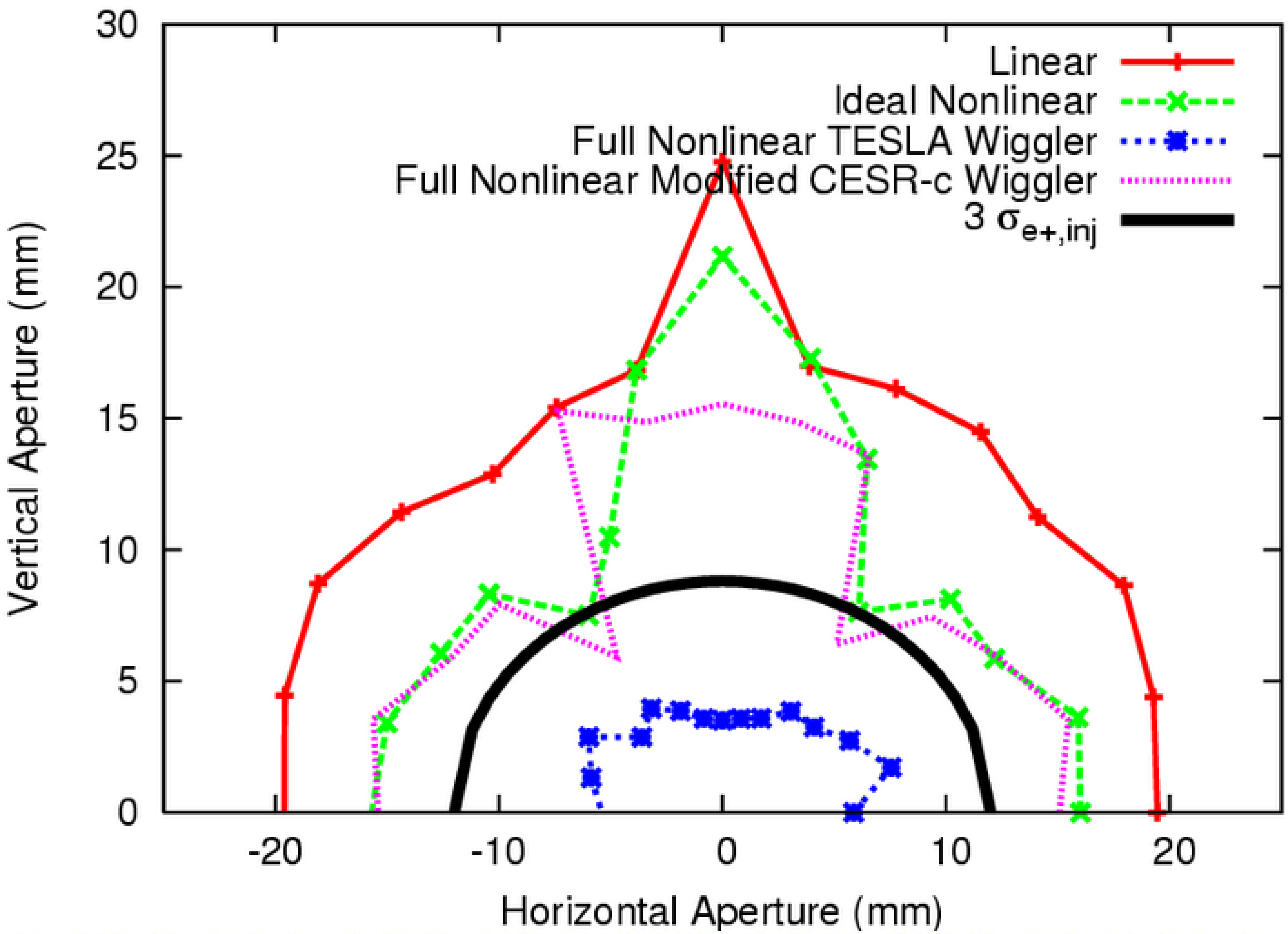
CESR-c Wiggler

Superferric magnet
NbTi coils with iron poles
$\Delta B_y/B_{peak}$ (x=10mm) = $7.7*10^{-5}$

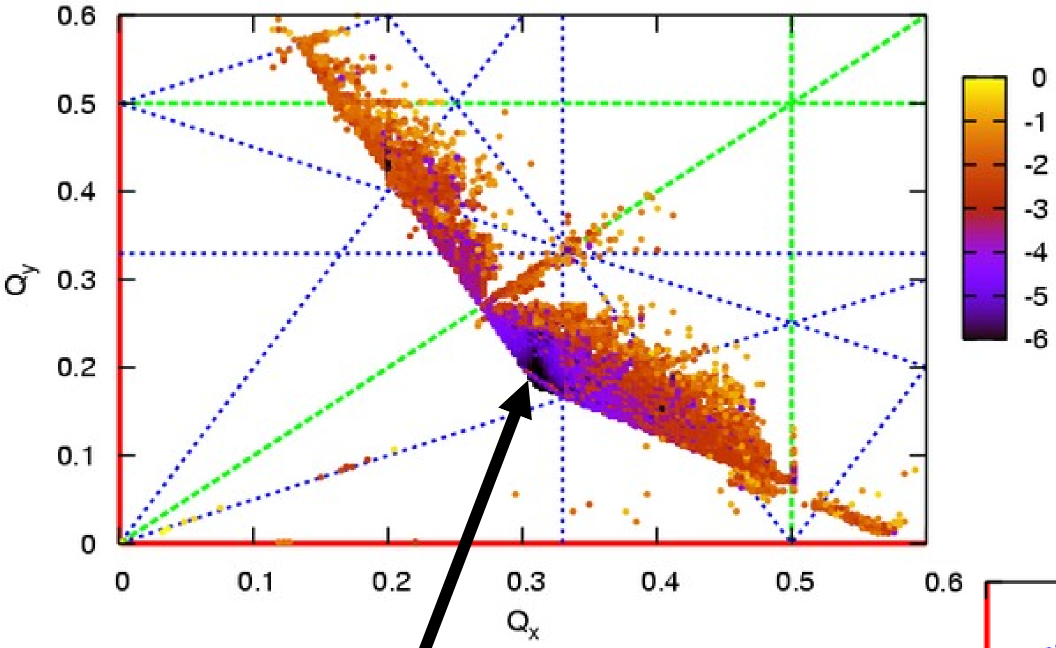




Dynamic Aperture



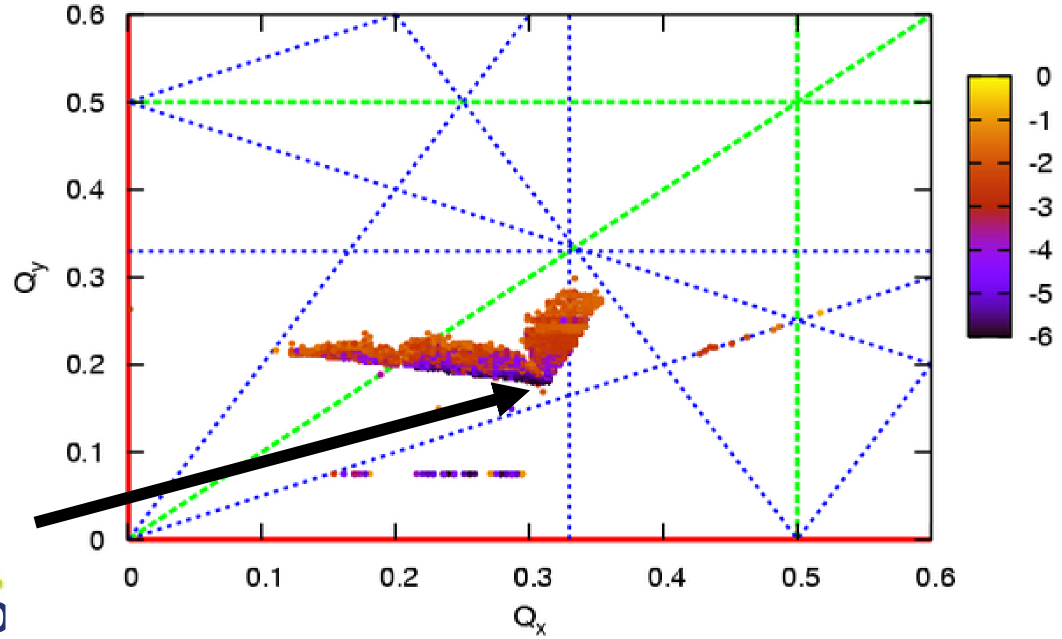
Frequency Map



$$color = \log\left(\sqrt{\Delta Q_x^{\ 2} + \Delta Q_y^{\ 2}}\right)$$

Operating point

Modified CESR-c Wiggler



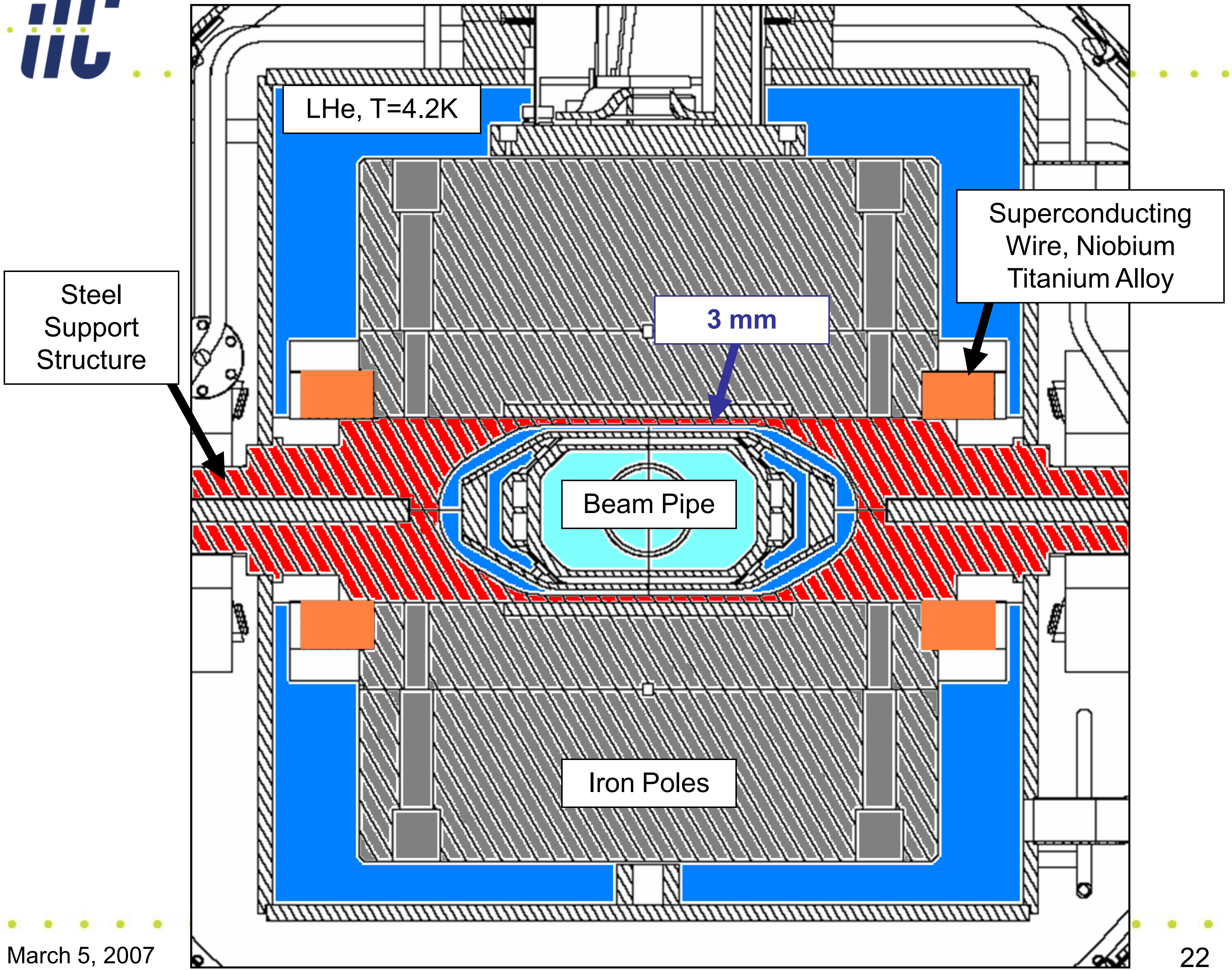
Operating point

Configuration/Costing for the RDR

- Design/Costing Reference
  - **Modified CESR-c Wiggler**
    - 14-pole
    - 2.5 m
- Costing Basis
  - **Based on detailed information from CESR-c wiggler production run**
  - **Documented M&S Costs**
    - Adjusted for additional poles
    - Adjusted for increased cold mass and cryostat length
    - Inflated for intervening years
  - **Production Techniques**
    - Fabrication and production line manpower requirements analyzed on a step-by-step basis
    - Adjusted for modified design
    - FTE requirements then re-calculated
  - **ED&I estimates**
    - Design work and documentation assume Magnet Group standard rates for complex devices (2 units, one for cryostat and one for cold mass)
    - Inspection requirements based on CESR-c wiggler quality control procedures

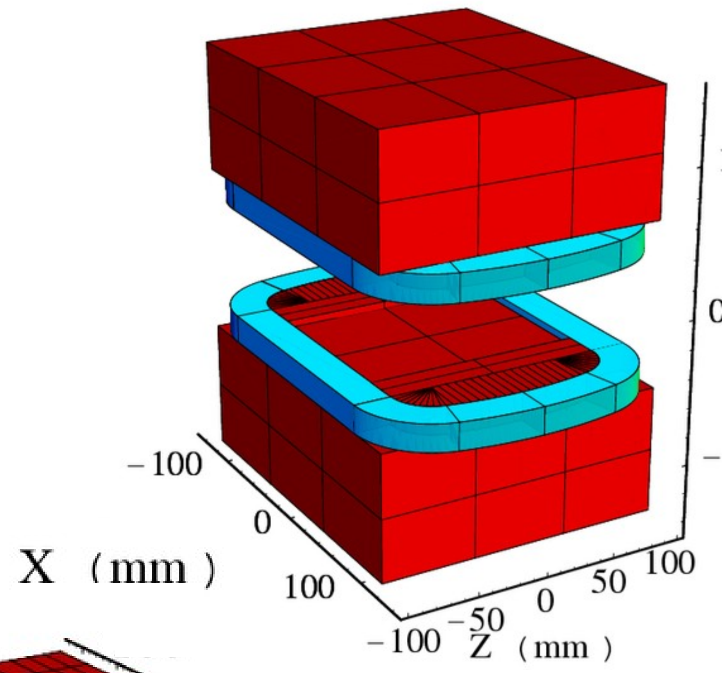
Looking Towards a Final Design

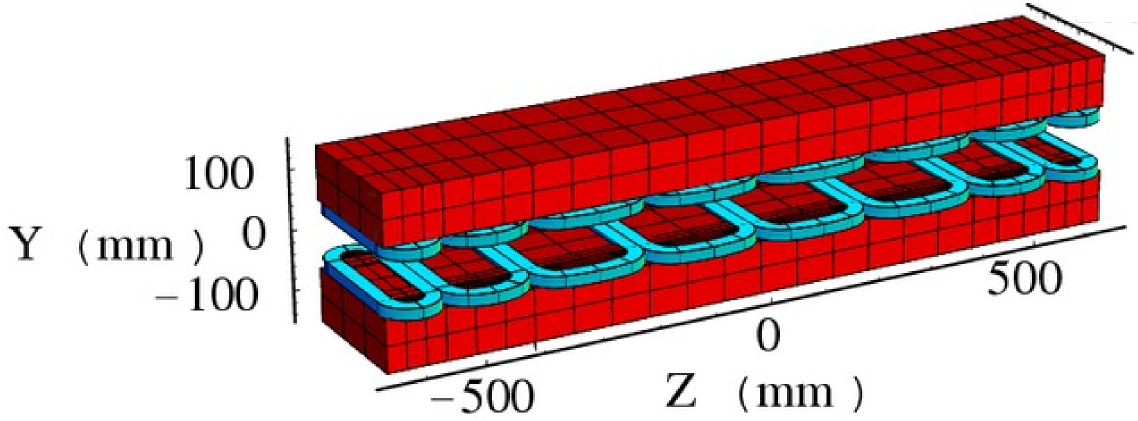
- Physics Optimization
  - **No. Poles**
  - **Period**
  - **Width**
  - **Gap**
  - **Peak Field**
- Engineering Issues
  - **Increased Length vs CESR-c design**
  - **Cryostat Vacuum Chamber Interface**
  - **Areas for engineering savings**
    - Bath cooling ⇨ Indirect cooling
    - Cold gas cooling of intermediate temperature shields
      - No LN_2 in ILC tunnel
    - More efficient coil winding system for large scale production


LHe, T=4.2K
Superconducting Wire, Niobium Titanium Alloy
Steel Support Structure
3 mm
Beam Pipe
Iron Poles

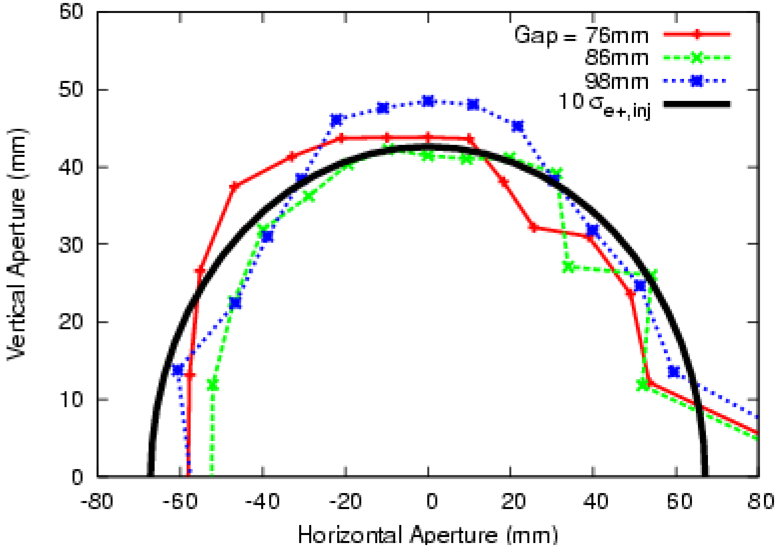
Magnet Modeling (J. Urban)

- OPERA 3-d → Radia
- Optimizations:
  - **Number of poles**
  - **Pole width**
  - **Pole gap**
  - **Period**
  - **Peak field**



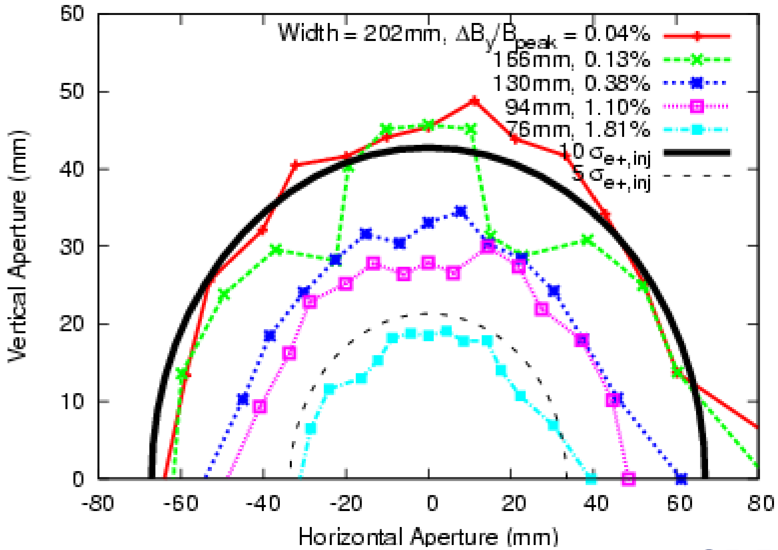


Optimizations



Gap can be raised to allow for thicker support plate

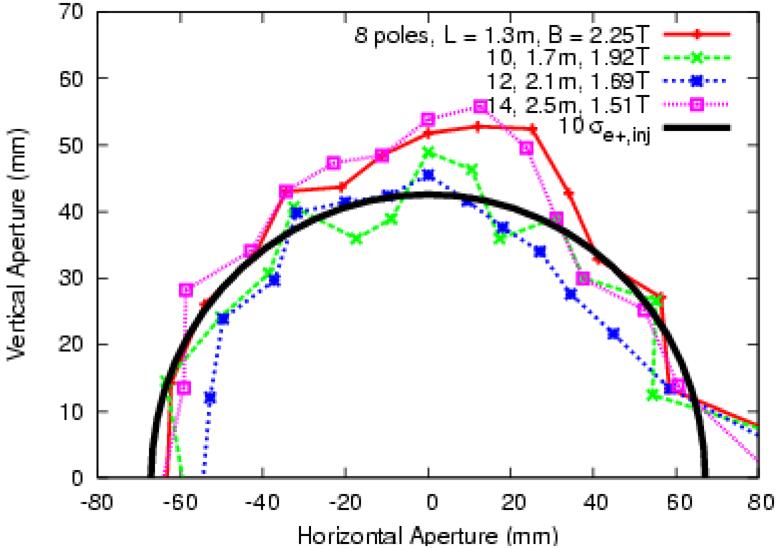
Recommendation:
Gap ≥ 86 mm

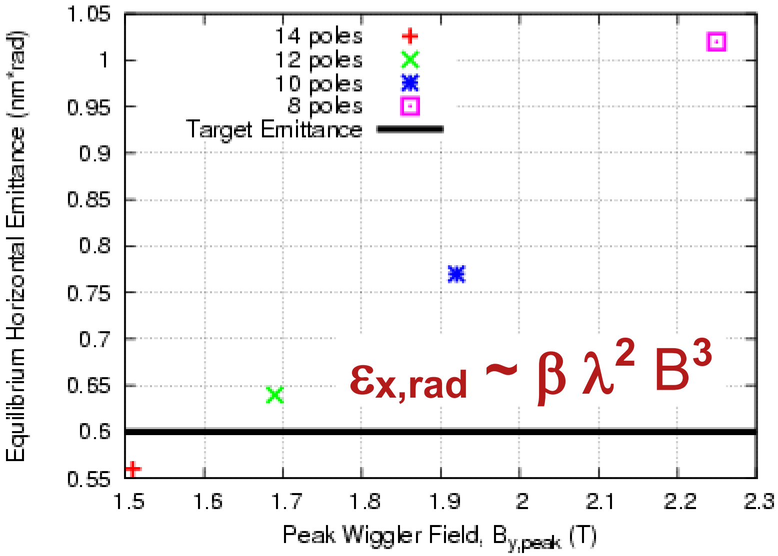


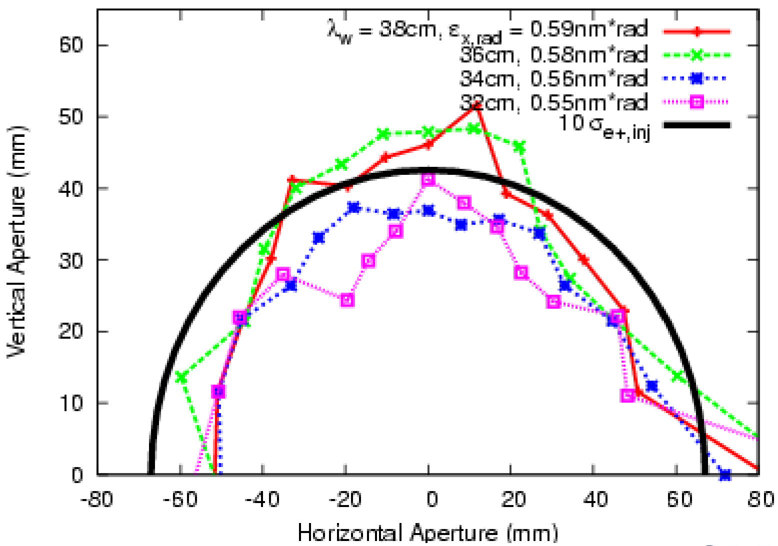
Narrower poles produce a smaller DA and require a redesigned support structure and vacuum chamber

Recommendation:
Width = 238 mm

Optimizations





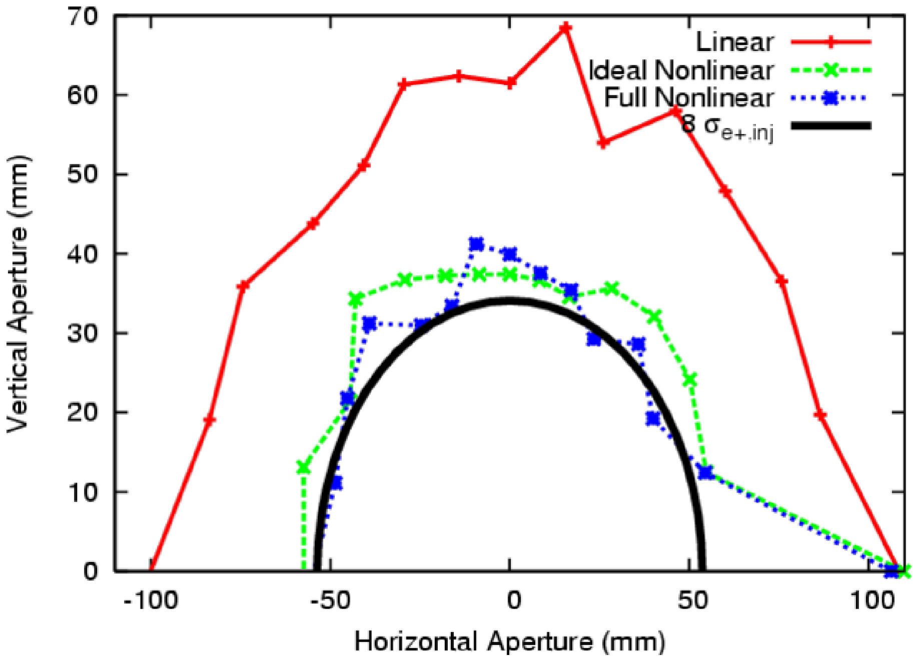


Fewer poles require higher fields which raises the emittance, a shorter period can counteract this with minimal DA degradation.

Recommendation:
12 poles and period = 32 cm

Recommendation

- Superferric ILC-Optimized CESR-c Wiggler
  - **12 poles**
  - **Period = 32 cm**
  - **Length = 1.68 m**
  - **$B_{y,peak}$ = 1.95 T**
  - **Gap = 86 mm**
  - **Width = 238 mm**
  - **I = 141 A**
  - **τ_{damp} = 26.4 ms**
  - **$\varepsilon_{x,rad}$ = 0.56 nm·rad**
  - **σ_δ = 0.13 %**



Misses nominal target (25 ms)

Engineering Issues

- Cryogenics Modifications
  - **Indirect cooling for cold mass**
  - **Switch to cold He gas for cooling thermal shields**
  - **42% of manpower for inner cryostat and stack assembly ⇨ significant cost reduction expected**
- Shorter Unit
  - **Simplified and more robust yoke assembly**
  - **Significant cost reduction**
    - 14 % fewer poles
    - 30% reduction in length
- Larger aperture
  - **Relaxed constraints on warm vacuum chamber interface with cryostat**

Conclusions

- Optimized design satisfies core physics requirements
- Expected to offer significant cost savings over RDR design
  - **Initial estimates give a cost reduction of order 25%**
- Optimized design configuration should significantly simplify final engineering design and provide more flexibility with the vacuum chamber interface
- Wiggler Information:

  https://wiki.lepp.cornell.edu/ilc/bin/view/Public/CesrTA/WigglerInfo