Conventional DC Magnets in the Beam Delivery System: their completeness in the RDR

Cherrill Spencer, SLAC

BDS Kick Off Meeting, October 11-13, 2007,SLAC

THIS VERSION HAS ALL ACTUAL COSTS BLANKED OUT

Functions of the ILC Beam Delivery System: results in many magnet styles

- The beam delivery system for the ILC
  - focuses electron and positron beams to nanometer sizes at the interaction point,
  - collimates the beam halo to provide acceptable backgrounds in the detector
  - has provision for state-of-the art beam instrumentation in order to reach the ILC's physics goals.
  - transports the spent beams to the main beam dumps.
- The corresponding beam lines have quite different magnetic requirements so the BDS has the most distinct magnet styles of any area, 66, even though it has the second lowest magnet quantity, 638.
- Consider the VALUE of the 476 conventional magnets in the BDS. [Next 6 slides are didactic w.r.t. "value"]

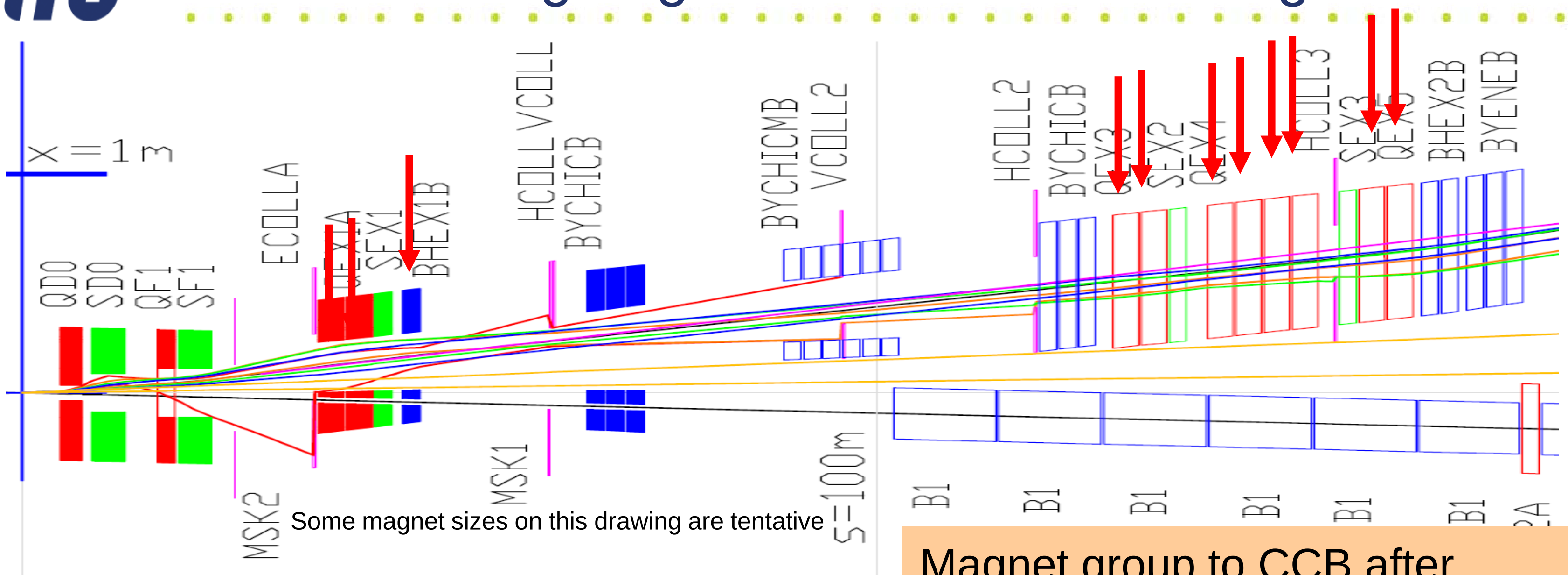
Understanding the concept of value as defined by the DOE (from "Value Management" [Revision G, Dec. 2004], in DOE's Project Management Practices,) page 1/2

- The fundamental approach of the Value Management (VM) process is to challenge everything and take nothing for granted; including the necessity of actually doing what is being proposed or what is currently being done.
- The worth of a project, program, or activity is the quality or virtue that makes that activity or product important to the customer.
- For the provider of the goods or services, the cost is the total expense associated with the production of the required function.
- A basic VM premise is : Anything providing less than the performance required by the user is not acceptable.

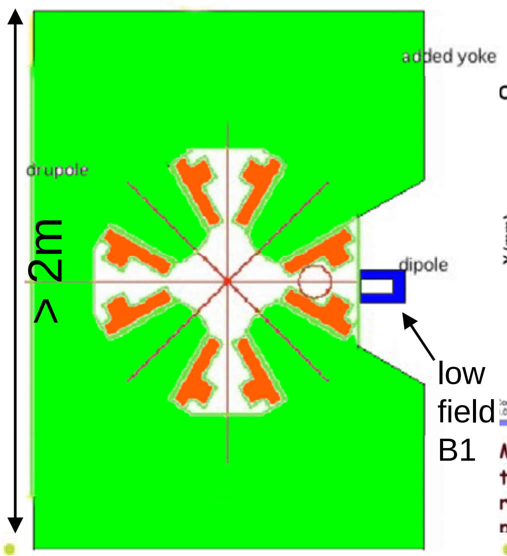
Understanding the concept of value as defined by the DOE (from "Value Management" [Revision G, Dec. 2004], in DOE's Project Management Practices,) page 2/2

- Value is the relationship of worth to cost in accordance with the ultimate customer's needs *and resources* in a given situation.
  - It is the *comparison* of the true cost of an activity, process, product, project, feature, or program to its worth as viewed by those involved (owners, users, and/or stakeholders).
- Value = Worth / Cost [has no dimensions]
- Optimum value is achieved when all criteria are met at the lowest overall cost
- BDS team has already applied VM process to the BDS magnet systems (in my opinion): see next 3 slides

Analyze the performance and cost of the 2mr crossing angle extraction beam magnets

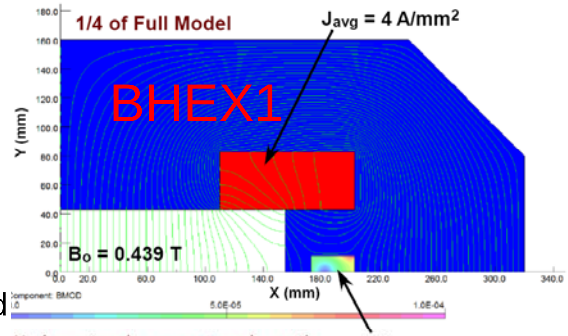


Some magnet sizes on this drawing are tentative



Recent suggestions by magnet tech group

Clear aperture is 305 x 80 mm for a 2.5 mm wall thickness

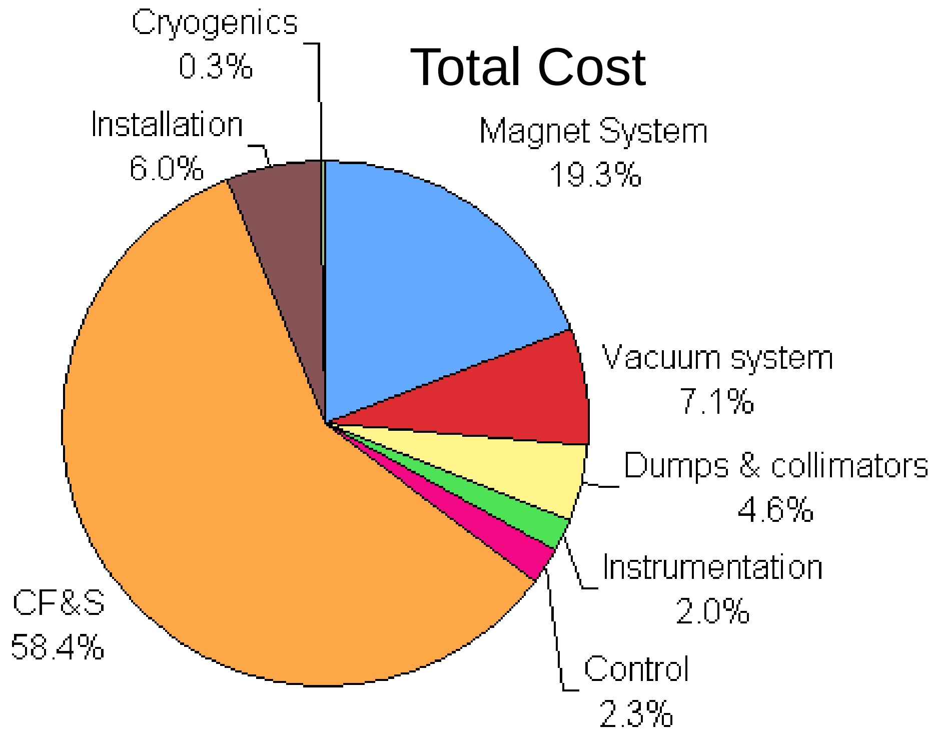


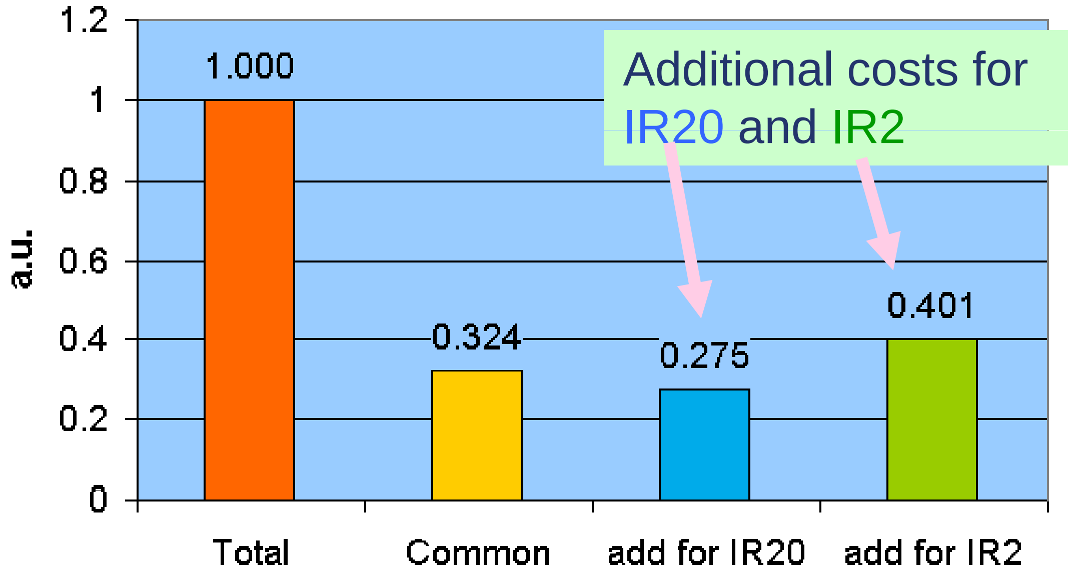
Make simple racetrack coils that go around poles and insert right/left cutouts with beam pipes during final assembly

Magnet group to CCB after Vancouver: "…there is still work that could be done to improve them further … but that by the nature of their aperture requirements and relative beamline spacing which arises naturally in the 2 mr layout, they will always be very challenging magnets that many experienced magnet designers place at the cusp of feasibility."

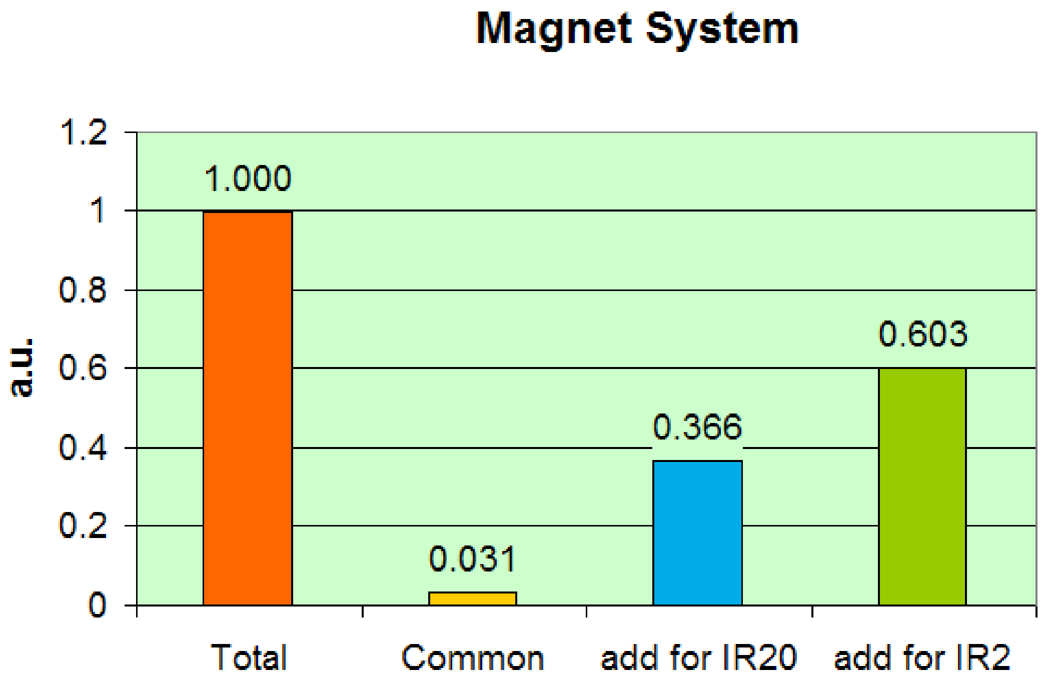
Drivers of the cost and Δcost

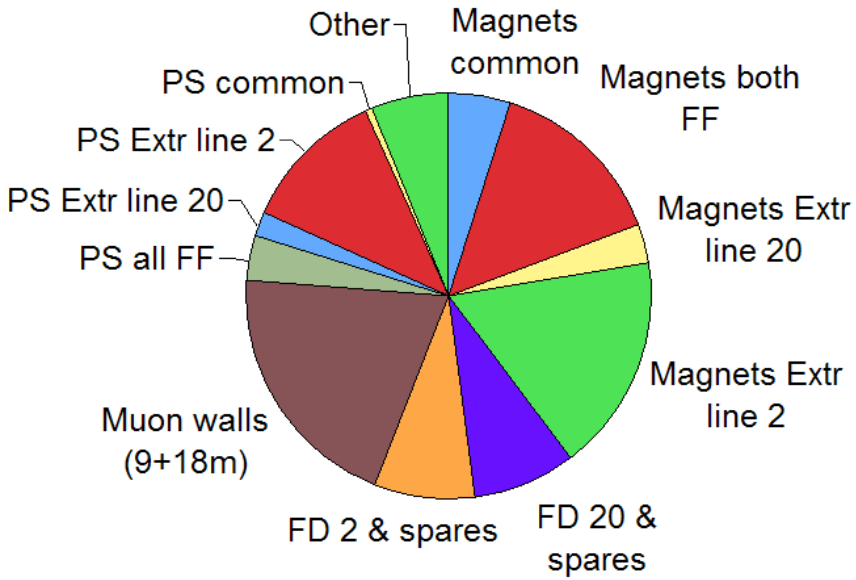
- Cost drivers with both 20 & 2 IPs
  - CF&S
  - Magnet system
  - Vacuum system
  - Installation
  - Dumps & Collimators.
- Drivers of splits between 20/2:
  - CF&S
  - Magnet system
  - Vacuum system
  - Dumps & collimators
  - Installation; Controls



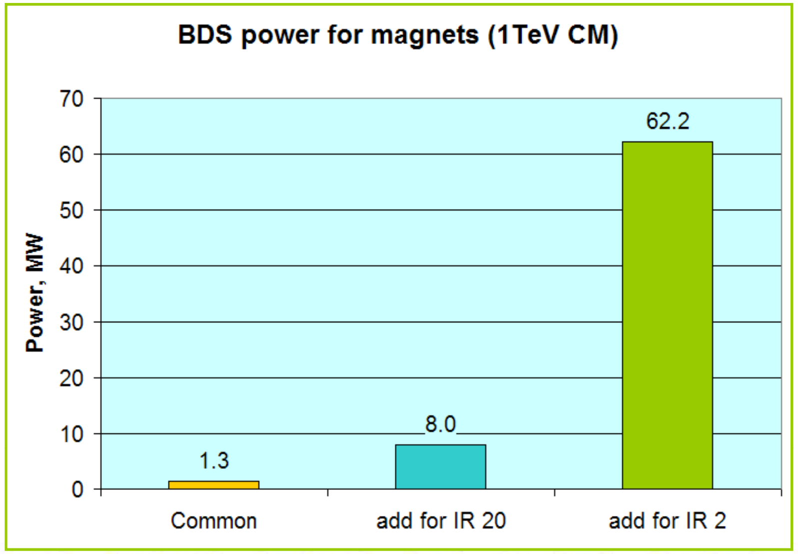


Magnet system: BDS 20/2





Larger number of huge 2mr extraction line magnets, uncertain feasibility & their very high kW power supplies cause the VALUE difference and so we decided to move the 2mr idea into the alternatives and change 20mr to 14mr. Later went to ONE IR.



Another change during RDR in BDS conventional magnets: reduction in length of muon walls: another value engineering e.g.

- Baseline config (18m+9m walls) reduce muon flux to < 10muons/200bunches if 0.1% of the beam is collimated
- Considered that
  - The estimation of 0.1% beam halo population is conservative and such high amount is not supported by any simulations
  - The min muon wall required for personnel protection is 5m
  - Detector can tolerate higher muon flux. With single 5m wall there is ~400muon/200bunches (500 GeV CM, 0.1% of the beam collimated) which corresponds to ~0.15% occupancy of TPC
  - Cost of long muon spoilers is substantial, dominated by material cost and thus approximately proportional to the muon wall length
- Suggested CCR to install initially only 5m single walls
  - The caverns will be built for full length walls, allowing upgrade if higher muons flux would be measured
  - Such upgrade could be done in ~3month
- MDI panel accepted this change: COST MUCH REDUCED

Evaluate the worth of the present lattices in the BDS: are all the magnets necessary for stated BDS functions?

- BDS lattice originally developed by Raimondi for NLC
- Mark Woodley is the beam physicist who transformed the bare transport parameters into do-able magnets (paying attention to poletip values, reasonable lengths, minimizing beam apertures)
- If challenged Woodley is able to explain why every magnet is necessary:
  - e.g. this many quads are needed to blow up the beam in the collimation section. To make the quads do-able had to increase the number of quads
  - the beam can't be too small in the laser wire section: affects magnet designs
- In some regions functions were combined to save tunnel length and reduce the number of magnets, e.g. polarimeter and diagnostic chicanes were combined into one chicane
- Virtually EVERY magnet in the BDS has to be working for the correct shaped beam to arrive at the interaction point!

ILC Magnet Summary Table

250Gev X 250Gev - 14 December 2006

LOOK HERE for BDS Summary

Magnet Type	Grand Totals		Sources			Damping Rings			2 RTML		2 Linacs		2 BeamDel	
	Styles	Quantity	Styles	e- Qty	e+ Qty	Styles	e- DR Qty	e+ DR Qty	Styles	Qty	Styles	Qty	Styles	Qty
Normal Conducting Dipole	22	1356	6	25	157	2	134	134	6	716	0	0	8	190
Normal Conducting Quad	37	4182	13	93	871	4	823	823	5	1368	0	0	15	204
Normal Conducting Sextupole	7	1050	2	0	32	2	504	504	0	0	0	0	3	10
Normal Cond Solenoid	3	50	3	12	38	0	0	0	0	0	0	0	0	0
Normal Cond Corrector	9	4047	1	0	871	3	540	540	4	2032	0	0	1	64
Pulsed/Kickers/Septa	11	227	0	0	19	5	46	46	1	52	0	0	5	64
NC Octupole/Muon Spoilers	3	8	0	0	0	0	0	0	0	0	0	0	3	8
Room Temperature Magnets	*92*	*10920*	*25*	*130*	*1988*	*16*	*2047*	*2047*	*16*	*4168*	*0*	*0*	*35*	*540*
Superconducting Quad	16	715	3	16	51	0	0	0	0	56	3	560	10	32
Superconducting Sextupole	4	12	0	0	0	0	0	0	0	0	0	0	4	12
Superconducting Octupole	3	14	0	0	0	0	0	0	0	0	0	0	3	14
Superconducting Corrector	14	1374	0	32	102	0	0	0	0	84	2	1120	12	36
Superconducting Solenoid	4	16	1	2	2	0	0	0	1	8	0	0	2	4
Superconducting Wiggler	1	160	0	0	0	1	80	80	0	0	0	0	0	0
Superconducting Undulator	1	42	1	0	42	0	0	0	0	0	0	0	0	0
Superconducting Magnets	*43*	*2333*	*5*	*50*	*197*	*1*	*80*	*80*	*1*	*148*	*5*	*1680*	*31*	*98*
Overall Totals	**135**	**13253**	**30**	**180**	**2185**	**17**	**2127**	**2127**	**17**	**4316**	**5**	**1680**	**66**	**638**

Overall Magnet Totals

250Gev X 250Gev - 14 December 2006

Category	*Styles*	*Totals*
Total Normal Conducting	92	10920
Total Superconducting	43	2333

This table summarizes the quantities of magnets as the ILC beamlines were configured in the Reference Design Report. These quantities are changing.

Requirements for each BDS magnet were documented in "parts lists" by Woodley. Each magnet had its own row in an EXCEL worksheet, uniquely identified by its X,Y,Z coordinates

Here is a sample of the "beam switchyard" quadrupole parts list that Spencer received from Woodley. Here are the magnetic requirements for each quad for a 250 GeV beam.

Subsystem	Function	Deck Name	Engineerin Type	Effective Length (m)	Pole-tip Radius (m)	Pole-tip Field (KG)	Gradient (KG/m)	Integrated Strength (KG)	Beam Energy (GeV)	Distance Along Beamline (n	Beam X (m)	Beam Y (m)	Beam Z (m)
EBSY1	QUAD	QMBSY1	QBDS4	3	0.04	3.254138	81.35346	244.060382	250	1.7	17.23545	0	-2224.28
EBSY1	QUAD	QMBSY1	QBDS4	3	0.04	3.254138	81.35346	244.060382	250	5	17.21235	0	-2220.98
EBSY1	QUAD	QMBSY2	QBDS4	3	0.04	-3.24728	-81.182	-243.54614	250	25.522345	17.06869	0	-2200.45
EBSY1	QUAD	QMBSY2	QBDS4	3	0.04	-3.24728	-81.182	-243.54614	250	28.822345	17.04559	0	-2197.15
EBSY1	QUAD	QF90C	QBDS4	3	0.04	4.768153	119.2038	357.611481	250	46.261508	16.92352	0	-2179.72
EBSY1	QUAD	QF90C	QBDS4	3	0.04	4.768153	119.2038	357.611481	250	49.561508	16.90042	0	-2176.42
EBSY1	QUAD	QD90C	QBDS4	3	0.04	-4.76815	-119.204	-357.61148	250	65.061508	16.79192	0	-2160.92
EBSY1	QUAD	QD90C	QBDS4	3	0.04	-4.76815	-119.204	-357.61148	250	68.361508	16.76882	0	-2157.62
EBSY1	QUAD	QF90	QBDS2	1	0.006	4.66435	777.3917	777.391675	250	82.861508	16.66732	0	-2143.12
EBSY1	QUAD	SQ1	QBDS1	0.5	0.006	0	0	0	250	95.306508	16.58021	0	-2130.67
EBSY1	QUAD	QD90	QBDS2	1	0.006	-4.66435	-777.392	-777.39167	250	98.369508	16.55877	0	-2127.61
EBSY1	QUAD	QF90	QBDS2	1	0.006	4.66435	777.3917	777.391675	250	113.87751	16.45021	0	-2112.1
EBSY1	QUAD	SQ2	QBDS1	0.5	0.006	0	0	0	250	126.32251	16.3631	0	-2099.66
EBSY1	QUAD	QD90	QBDS2	1	0.006	-4.66435	-777.392	-777.39167	250	129.38551	16.34166	0	-2096.59
EBSY1	QUAD	QF180	QBDS3	2	0.006	3.191863	531.9771	1063.9542	250	140.45314	16.26418	0	-2085.53
EBSY1	QUAD	QD180	QBDS3	2	0.006	-2.39242	-398.737	-797.4745	250	151.41396	16.18746	0	-2074.57
EBSY1	QUAD	QF180	QBDS3	2	0.006	3.191863	531.9771	1063.9542	250	162.37479	16.11073	0	-2063.6
EBSY1	QUAD	SQ3	QBDS1	0.5	0.006	0	0	0	250	170.37942	16.0547	0	-2055.6

Spencer used her magnet engineering expertise to *conceptually design* magnets that matched these requirements and had enough aperture space for a beampipe : see next slide.

Here is same list of quad magnets, with magnetic requirements scaled to focus 500GeV beams and

larger apertures to accommodate beampipes, core length specified and water cooled coils designed with a particular shape of conductor so that current, voltage and cooling water have been calculated.

Subsystem Name	Deck Name	Pole-tip Field (at 500GeV/be	Gradient(kG/m) at 500GeV/beam	Intgrtd Strnght(kG) at 500GeV/beam	Distance Along Beamline (m)	Magnet Z (m)	Engineering Magnet Style	Current amps at 500GeV/beam	Voltage at 500GeV/beam	Total LCW at 180 psi, gpm
EBSY1	QMBSY1	6.508277	162.706921	488.1207634	1.7	-2224.28	Q85L2960	426	101.3	12.2
EBSY1	QMBSY1	6.508277	162.706921	488.1207634	5	-2220.98	Q85L2960	426	101.3	12.2
EBSY1	QMBSY2	-6.49456	-162.36409	-487.0922778	25.5223454	-2200.45	Q85L2960	426	101.3	12.2
EBSY1	QMBSY2	-6.49456	-162.36409	-487.0922778	28.8223454	-2197.15	Q85L2960	426	101.3	12.2
EBSY1	QF90C	9.536306	238.407654	715.222961	46.2615081	-2179.72	Q85L2960	624.2	148.4	12.2
EBSY1	QF90C	9.536306	238.407654	715.222961	49.5615081	-2176.42	Q85L2960	624.2	148.4	12.2
EBSY1	QD90C	-9.53631	-238.40765	-715.222961	65.0615081	-2160.92	Q85L2960	624.2	148.4	12.2
EBSY1	QD90C	-9.53631	-238.40765	-715.222961	68.3615081	-2157.62	Q85L2960	624.2	148.4	12.2
EBSY1	QF90	9.3287	1554.78335	1554.78335	82.8615081	-2143.12	Q16L992	400.7	20.5	1.5
EBSY1	SQ1	0	0	281.3	95.3065081	-2130.67	QS16L492	400	10	1
EBSY1	QD90	-9.3287	-1554.7833	-1554.78335	98.3695081	-2127.61	Q16L992	400.7	20.5	1.5
EBSY1	QF90	9.3287	1554.78335	1554.78335	113.877508	-2112.1	Q16L992	400.7	20.5	1.5
EBSY1	SQ2	0	0	281.3	126.322508	-2099.66	QS16L492	400	10	1
EBSY1	QD90	-9.3287	-1554.7833	-1554.78335	129.385508	-2096.59	Q16L992	400.7	20.5	1.5
EBSY1	QF180	6.383725	1063.9542	2127.908406	140.453139	-2085.53	Q16L1992	274.2	26	3.1
EBSY1	QD180	-4.78485	-797.4745	-1594.949	151.413965	-2074.57	Q16L1992	205.5	19.5	3.1
EBSY1	QF180	6.383725	1063.9542	2127.908406	162.374791	-2063.6	Q16L1992	274.2	26	3.1
EBSY1	SQ3	0	0	281.3	170.379422	-2055.6	QS16L492	400	10	1

N.B. ONLY ONE QUAD STYLE HAD A COMPUTER MODEL MADE BY POISSON: this provided the detailed core shape, size and hence, weight. All other quad styles' core sizes were scaled from this one REFERENCE QUAD.

Assess the technical maturity of the BDS conventional magnet designs

- Not a single BDS conventional magnet style was turned from its conceptual design (described in the previous slide) into a set of engineering drawings !
- However the magnets are almost all quite straightforward and I am not concerned by the lack of engineering carried out on them for the RDR.
- Although ATF2 is an ILC/FF test facility it is not contributing to knowledge of the design of the FF magnets because I am mostly re-using old SLAC magnets to save money.
  - I am learning the vagaries of designing a magnet in one country, fabricating it in a 2^{nd} and operating it in a 3rd
- During my EDR planning talk I will address what needs to be done during the EDR stage

Assumptions for cost estimating the ILC magnets during the RDR process:

For cost-estimating purposes we assumed:

- Magnet modeling, designing and engineering is being done at HEP labs (e.g. SLAC, FNAL, JINR, LBL, BNL etc)
- All the magnet drawings are being done at same HEP labs
- Magnets are being fabricated "to ILC prints"
  - i.e. NOT being fabricated based only on specifications
- Almost all magnets are being fabricated by a wide variety of commercial companies all over the world. A few very complex ones will be made at some HEP labs.
- Almost all magnets will be QC'd and magnetically measured at the ILC site.
  - So magnet engineering hours include magnetic design; working with mechanical designer, manufacturer, PS engineer, Alignment, Installation team; writing travellers & measurement plan; following incoming QC and magnetic measurements

Material costs and fabrication labor costs were merged into two fixed costing coefficients

- Copper cost in our RDR estimates was $3.59 per lb (that's just the copper itself, added the fabrication into conductor cost, insulation cost and epoxy cost to get a conductor cost / lb)
- Steel cost in our RDR estimates was $0.5 per lb of raw low carbon steel plate
- Used low (non-USA) hourly labor rates for the fabrication labor : one could argue with rates chosen
- Analyzed past machine's magnet costs to develop the present-day fixed costing coefficients : used just 2 for expediency. Needs to be a range of costing coefficients- see my EDR planning talk for more details.

BASES of RDR COST ESTIMATES for the BDS conventional magnets

- WATER COOLED MAGNETS: Conceptual design & internal estimate using fixed costing coefficients: $33/lb of coil and $7/lb of steel + assembly labor
- SOLID WIRE MAGNETS: Conceptual design & internal estimate using fixed costing coefficients: $9/lb of coil and $7/lb of steel + assembly labor
- MUON SPOILERS: Conceptual design & internal estimate using $0.61/lb of steel and $0.74/ft of cable + assembly labor

BDS Conventional Magnet Unit Costs developed as described in previous 3 slides. COSTS BLANKED OUT

Magnet Style	Magnet Unit Cost	Number Req	Total Magnet Cost	Mover Unit Cost	No. Movers Req	Total Mover Cost	Stand Unit Cost	Total Stand Cost	Total Cost
BDS Conventional Magnets									
D66L100		64						$0	$0
D66L2334		114						$0	$0
D45L1995		4						$0	$0
D25L2375		24						$0	$0
D24L2976V2		12						$0	$0
D172L1830		16						$0	$0
D172L228		8						$0	$0
D172L628		4						$0	$0
D272L1728		8						$0	$0
Q85L2960		30			30			$0	$0
Q16L992		38			38			$0	$0
QS16L492		8			8			$0	$0
Q16L1992		6			6			$0	$0
Q24L1488		8			8			$0	$0
Q45L1980		14			14			$0	$0
Q30L1985		14			14			$0	$0
Q26L1990V1		52			52			$0	$0
Q65L1968		6			6			$0	$0
QS24L288		2			2			$0	$0
Q90L2100		10			10			$0	$0
Q112L2244		4			4			$0	$0
Q132L2134		2			2			$0	$0
Q150L1925		2			2			$0	$0
Q178L2011		8			8			$0	$0
SX85L958		4						$0	$0
SX24L988		2						$0	$0
SX30L970		4						$0	$0
EO30L790		4						$0	$0
5m Muon Spoiler		2						$0	$0
BDS Magnet Total Cost		572			218				

How "Engineering, Design & Inspection : ED&I" was estimated for BDS conventional magnets

In this public version of my presentation I have deleted all actual $ costs, per ILC policy.

Complexity of magnet. Cost of ED&I /style	Magnet Engineer, Hours/style	Mechanical Designer, Hours/style	Alignment Engineer, Hours/style
Simple, e.g. Corrector, solid wire quad $XK	120	400 (~10 drawings)	24
Moderate, e.g. small water cooled quad, std dipole $YK	320	900 (~ 30 drawings)	40
Complex e.g. gradient dipole; septa; extraction. $ZK	1040	1500 (~50 drawings)	160

Used SLAC FY06 labor rates and above hours to calculate ED&I $/style. Did not include all tasks or systems engineering in these hours. Have re-done ED&I for the real magnet design phase: will show results in my EDR planning talk on Saturday.

Estimate inaccuracies in the cost estimates: labor is main culprit

Magnet Engineering Name (Style)	Uncertainty in Estimate (%)	Probability Distribution shape, symmetry	% of overall cost = Copper	Steel	Super-conductor	Labor	Correlations Designer-Estimator
BDS Conventional Magnets							
D66L100	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D66L2334	(-10 % + 40%)	Asymmetric triangle	6.8	5.2		86.6	Spencer
D45L1995	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D25L2375	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D24L2976V2	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D172L1830	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D172L228	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D172L628	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
D272L1728	(-10 % + 40%)	Asymmetric triangle	4.7	3.8		78.6	Spencer
Q85L2960	(-10 % + 40%)	Asymmetric triangle	5	5.3		73.7	Spencer
Q16L992	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
QS16L492	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q16L1992	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q24L1488	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q45L1980	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q30L1985	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q26L1990V1	(-10 % + 40%)	Asymmetric triangle	2.1	5.2		85.7	Spencer
Q65L1968	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
QS24L288	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q90L2100	(-10 % + 40%)	Asymmetric triangle	5.2	3.3		75.5	Spencer
Q112L2244	(-10 % + 40%)	Asymmetric triangle	5.7	3		73.3	Spencer
Q132L2134	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q150L1925	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
Q178L2011	(-10 % + 40%)	Asymmetric triangle	4.5	4.2		77.1	Spencer
SX85L958	(-10 % + 40%)	Asymmetric triangle	1.4	3.4		91	Spencer
SX24L988	(-10 % + 40%)	Asymmetric triangle	1.4	3.4		91	Spencer
SX30L970	(-10 % + 40%)	Asymmetric triangle	1.4	3.4		91	Spencer
EO30L790	(-10 % + 40%)	Asymmetric triangle	1.4	3.4		91	Spencer
5m Muon Spoiler	(-5% + 20%)	Asymmetric triangle	0.1	94.8		5.1	Jung/Spencer

Justification for "inaccuracies" in conventional magnet costs: recent examples

Potential vendor	Proposed price for a medium sized dipole, total quantity of 3. $
Foreign institution A	$A
Foreign institution B	$B
USA commercial company C	$C
USA commercial company D	$D
USA institution E	$E
USA commercial company F	$F

Full drawing set provided to bidders

Highest/lowest = 1.86

Range of USA quotes:

+/-6% around average

Recent LCLS experience

With dipole of ~ same gap and field, 1/3 length.

Quantity 4

Cost included magnetic design, drawings & mag measurements.

Unit cost ranged from $P to nearly $6xP

Uncertainty in future material prices

- **Cost Risks caused by volatile materials prices:**

Copper price risk mitigation :

Buy Cu for all magnets as soon as possible

Copper vendor to hold inventory, release as needed to magnet fabricators

This requires front loaded funding profile- funds needed EARLY on, not spread equally through the ~ 7 year construction period

5 year copper prices:

Copper has gone up by 4.5 times its 2002 cost.

No-one can say what it will be by ~ 2010

Other causes of uncertainty in cost estimates

- NOT a problem: checking of counts, unit & total costs amongst Garbincius, Seryi & Spencer showed excellent agreement
- There will always be variation in estimates from magnet vendors
  - We saw a ~25% spread among 3 experienced vendors based on the one detailed design for an RTML magnet we submitted for “budgetary quotes”- even though it was for a very large quantity: 1650 quads.
  - Give them longer to prepare their bids [establish their material availability etc] and the spread in costs will decrease
    - Might expect to decrease the ±20-30% to ±10-20% if we have a significant increase in engineering & design resources to carry out more detailed estimates
  - Systematics:
    - Reliability and radiation lifetime requirements will increase cost
    - Rapidly increasing Cu cost
    - Decrease in number of styles (consistent with Area System requirements) will reduce costs
  - If the definitions of magnet requirements change, then so will the cost
    - BDS BASIC magnet requirements are very clearly provided at this time
    - Field quality and alignment tolerances yet to be provided to Magnet System Group

Performance Acceptability of BDS Magnets

- Risks affecting the magnet performance
  - Technical – none are judged to be too high or insoluble (assuming requirements are reasonable)
  - main technical issues with BDS magnets are their positional and field strength stabilities. Thermal and mechanical disturbances will be minimized by stabilizing the BDS tunnel air temperature to 0.5ºC, the cooling water to 0.1ºC , and limiting high frequency vibrations due to local equipment to the order of 10 nm.
  - During the EDR phase will quantify the LCW and air temperature stability requirements; do value engineering to choose requirements & minimize cost
  - Improve the lifetime of the materials in a radiation environment
  - Reliability

Note: radiation lifetimes requirements can only increase cost, some design features for increased reliability will increase cost, others can decrease cost (Spencer's experience)

Can we design & build magnets with the required performance?

- Magnetic performances are achievable, BUT:
- Reliability – translates into cost uncertainty
  - FMEA (Failure Mode and Effect Analysis) needs to be carried out on selected typical styles
    - Determine critical components
    - Plan lifetime tests, R&D studies for improvement of materials & components
  - Effects of Radiation on magnet materials
    - Determine sections with high dose rates
    - Investigate materials that can resist radiation better than most
      - Insulation
      - Epoxies
      - Etc.

What Magnet System Group needs to do during EDR stage: more on this on Saturday

- Worldwide Magnet Production Capability
  - Existing vendor capacities are limited
  - Significant increase in production facilities comes with increased costs
    - Infrastructure – buildings, tooling, etc.
    - Staffing – hiring, training costs, etc.
    - Again, more front loading of funding profile
    - Smaller, ‘traditional’ magnet vendors do not want to scale up for a 3-4 year production period; a “one time” occurrence
  - Need to develop a realistic production model with assessment of funding, resources and commercial risks
    - Note: if engineering designs are not available at start of the real (funded) 'project' stage, magnet production will be pushed ‘downstream’ and will impact vendors, staffing, testing, and installation: “pile-up”...