Ring to Main Linac Magnets

V. Kashikhin for ILC Meeting

(with some JCT additions)

August 27, 2007

General Information for RTML Magnets

The vast majority of RTML magnets are room-temperature electromagnets. There are a few quads and dipole corrector magnets which are inside the BC1 and BC2 cryomodules, these are necessarily superconducting. There are also 4 superconducting solenoid magnets in the spin rotator which are superconducting.

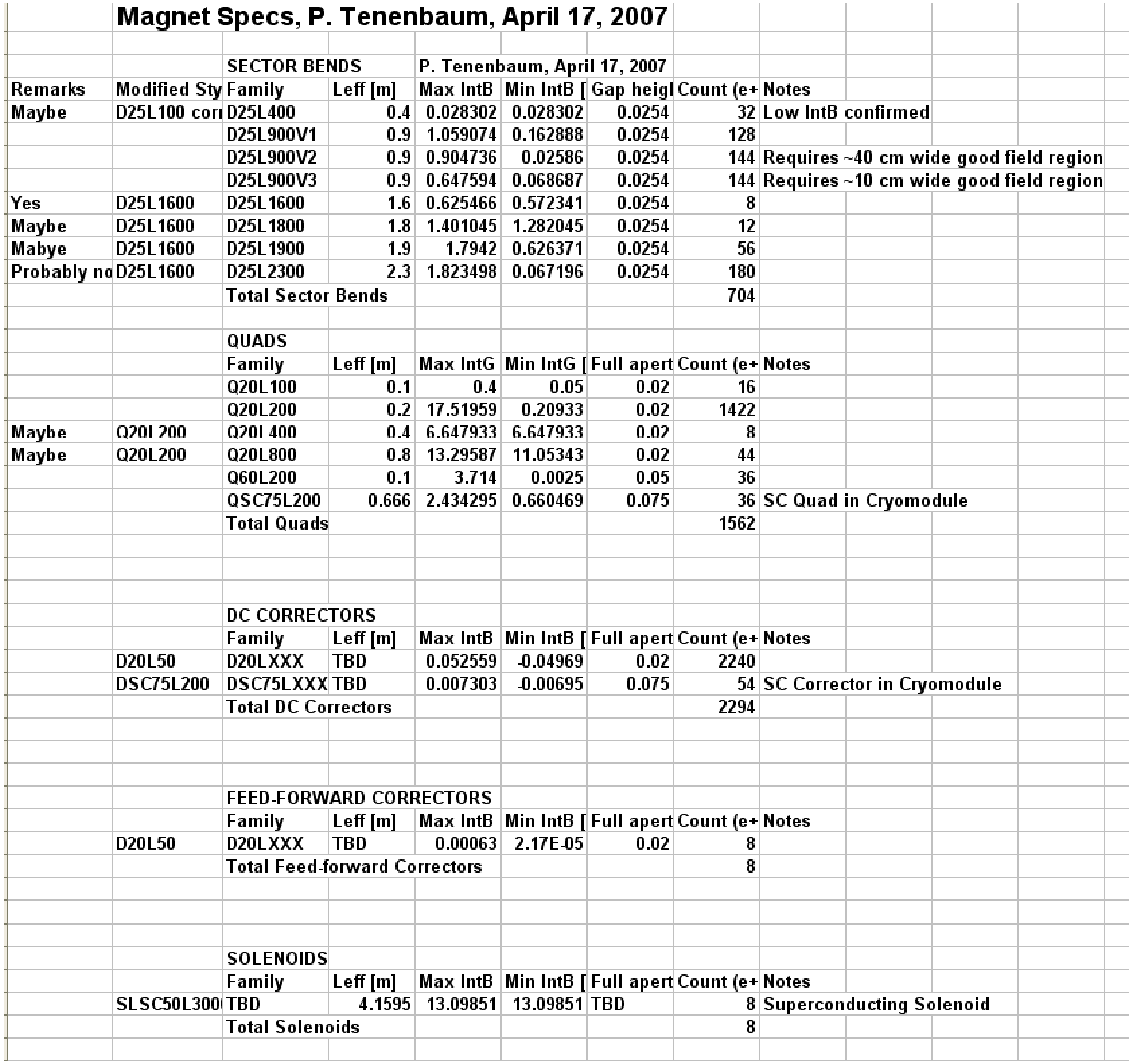
Most of the quadrupole magnets must be capable of performing beam-based alignment (BBA). In particular, each quad must have the capability of being reduced in strength by 20% from its nominal strength. In the current design we have chosen to achieve this by giving each quadrupole its own power supply. In addition, the center stability of the quadrupole over the aforementioned 20% reduction in strength must be at the level of 1-2 micrometers.

Each dipole corrector has its own power supply. Bend magnets and solenoids are generally powered in strings.
There are no magnet movers in the RTML.

Most warm magnets have a full aperture of 2 cm and all cold magnets have a full aperture of 7.5 cm (or whatever is eventually decided for the linac quads). A few magnets in the BC1/BC2 extraction line have larger apertures to accomodate the large beams in these regions. The BC1 and BC2 bend magnets are special in that their bending angles must be varied in order to adjust the momentum compaction (and thus the compression factor) of their systems. This implies that the path through the magnets in the horizontal plane is a function of the bunch compressor settings; this further implies that the bend magnets have to have a very wide opening with a good field over a considerable fraction of that opening – in particular the BC1 bends need a 40 cm wide aperture, while the BC2 bends need a 10 cm wide aperture; but both sets of bends can tolerate an aperture which is only 2 cm tall. Apertures here refer to pole-piece apertures, not vacuum chamber apertures.

Most magnets in the RTML are DC magnets. A few of them are pulsed bends (which need to come on in the intra-train period of 200 msec), some others are kickers (which need to come on in the 150 nsec intra-bunch period), and a couple are corrector magnets for the steering feed-forward which need to be able to change their field on a bunch-by-bunch timescale within a train. Finally, there are “raster” correctors which keep the bunches from all hitting the same spot on the dump window. This may not be necessary, but it seems prudent to reduce the stress on the dump window as much as possible.
(RTML WEB Site)

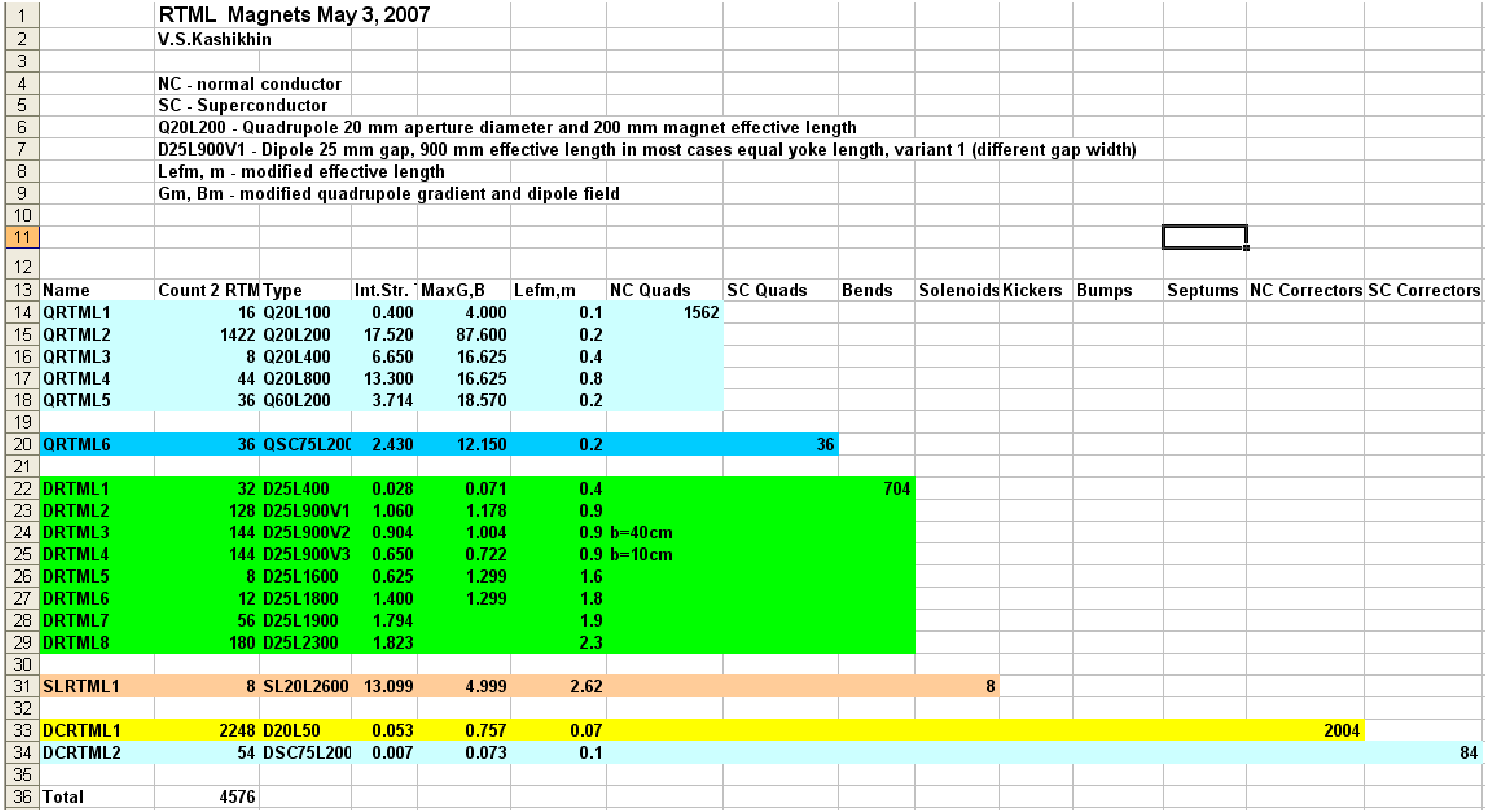
RTML Magnet Specifications



Magnet Specs, P. Tenenbaum, April 17, 2007

		SECTOR BENDS		P. Tenenbaum, April 17, 2007				
Remarks	Modified Sty	Family	Leff [m]	Max IntB	Min IntB [	Gap heigl	Count (e+	Notes
Maybe	D25L100 corı	D25L400	0.4	0.028302	0.028302	0.0254	32	Low IntB confirmed
		D25L900V1	0.9	1.059074	0.162888	0.0254	128	
		D25L900V2	0.9	0.904736	0.02586	0.0254	144	Requires ~40 cm wide good field region
		D25L900V3	0.9	0.647594	0.068687	0.0254	144	Requires ~10 cm wide good field region
Yes	D25L1600	D25L1600	1.6	0.625466	0.572341	0.0254	8	
Maybe	D25L1600	D25L1800	1.8	1.401045	1.282045	0.0254	12	
Mabye	D25L1600	D25L1900	1.9	1.7942	0.626371	0.0254	56	
Probably nc	D25L1600	D25L2300	2.3	1.823498	0.067196	0.0254	180	
		Total Sector Bends					704	
		QUADS						
		Family	Leff [m]	Max IntG	Min IntG [	Full apert	Count (e+	Notes
		Q20L100	0.1	0.4	0.05	0.02	16	
		Q20L200	0.2	17.51959	0.20933	0.02	1422	
Maybe	Q20L200	Q20L400	0.4	6.647933	6.647933	0.02	8	
Maybe	Q20L200	Q20L800	0.8	13.29587	11.05343	0.02	44	
		Q60L200	0.1	3.714	0.0025	0.05	36	
		QSC75L200	0.666	2.434295	0.660469	0.075	36	SC Quad in Cryomodule
		Total Quads					1562	
		DC CORRECTORS						
		Family	Leff [m]	Max IntB	Min IntB [	Full apert	Count (e+	Notes
	D20L50	D20LXXX	TBD	0.052559	-0.04969	0.02	2240	
	DSC75L200	DSC75LXXX	TBD	0.007303	-0.00695	0.075	54	SC Corrector in Cryomodule
		Total DC Correctors					2294	
		FEED-FORWARD CORRECTORS						
		Family	Leff [m]	Max IntB	Min IntB [	Full apert	Count (e+	Notes
	D20L50	D20LXXX	TBD	0.00063	2.17E-05	0.02	8	
		Total Feed-forward Correctors					8	
		SOLENOIDS						
		Family	Leff [m]	Max IntB	Min IntB [	Full apert	Count (e+	Notes
	SLSC50L300	TBD	4.1595	13.09851	13.09851	TBD	8	Superconducting Solenoid
		Total Solenoids					8	

RTML Magnet Styles



RTML Magnets May 3, 2007

V.S.Kashikhin

NC - normal conductor

SC - Superconductor

Q20L200 - Quadrupole 20 mm aperture diameter and 200 mm magnet effective length

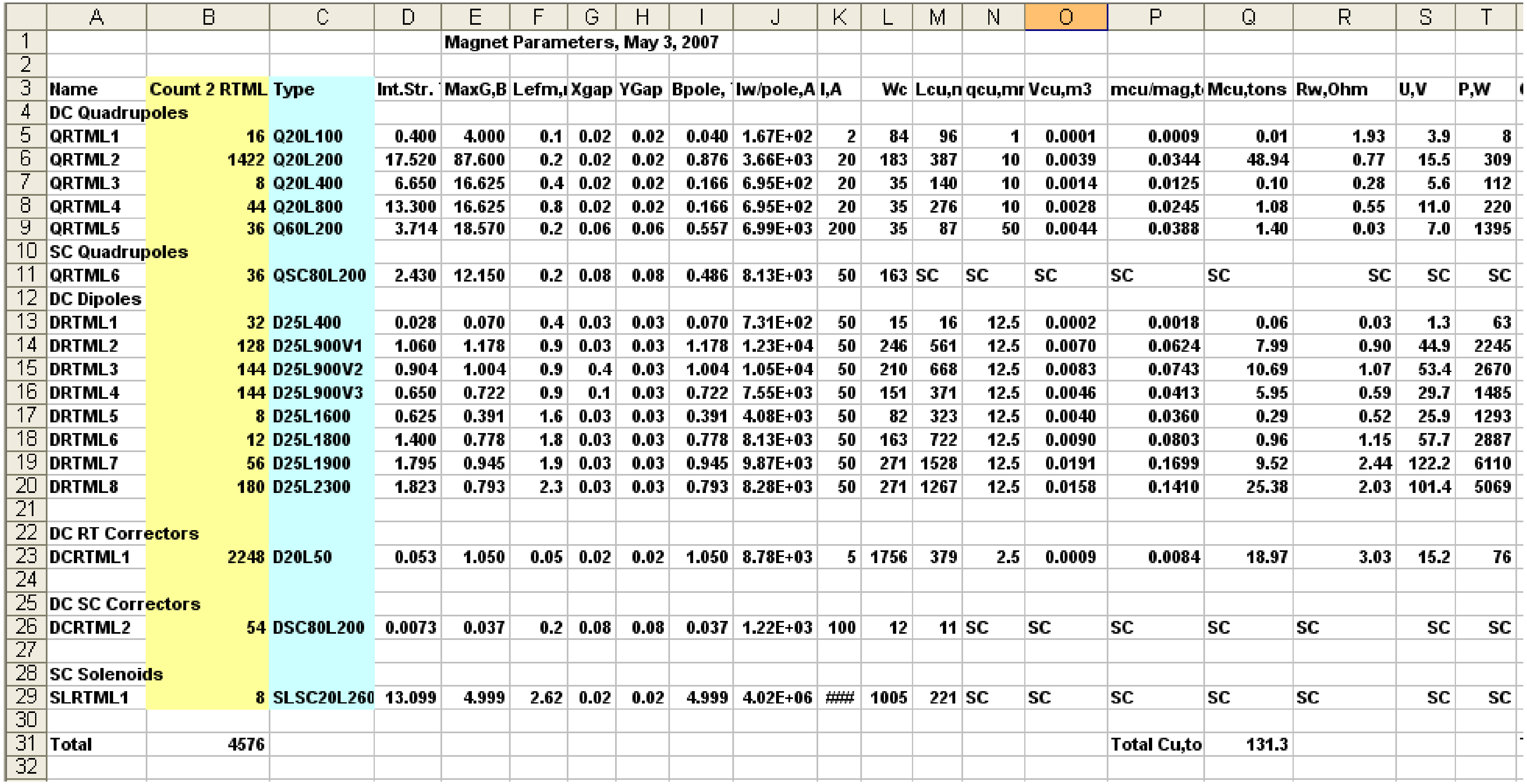
D25L900V1 - Dipole 25 mm gap, 900 mm effective length in most cases equal yoke length, variant 1 (different gap width)

Lefm, m - modified effective length

Gm, Bm - modified quadrupole gradient and dipole field

Name	Count 2 RTM	Type	Int.Str.	MaxG,B	Lefm,m	NC Quads	SC Quads	Bends	Solenoids	Kickers	Bumps	Septums	NC Correctors	SC Correctors
QRTML1	16	Q20L100	0.400	4.000	0.1	1562								
QRTML2	1422	Q20L200	17.520	87.600	0.2									
QRTML3	8	Q20L400	6.650	16.625	0.4									
QRTML4	44	Q20L800	13.300	16.625	0.8									
QRTML5	36	Q60L200	3.714	18.570	0.2									
QRTML6	36	QSC75L20	2.430	12.150	0.2		36							
DRTML1	32	D25L400	0.028	0.071	0.4			704						
DRTML2	128	D25L900V1	1.060	1.178	0.9									
DRTML3	144	D25L900V2	0.904	1.004	0.9	b=40cm								
DRTML4	144	D25L900V3	0.650	0.722	0.9	b=10cm								
DRTML5	8	D25L1600	0.625	1.299	1.6									
DRTML6	12	D25L1800	1.400	1.299	1.8									
DRTML7	56	D25L1900	1.794		1.9									
DRTML8	180	D25L2300	1.823		2.3									
SLRTML1	8	SL20L2600	13.099	4.999	2.62				8					
DCRTML1	2248	D20L50	0.053	0.757	0.07								2004	
DCRTML2	54	DSC75L200	0.007	0.073	0.1									84
Total	4576													

RTML Magnet Parameters



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1					Magnet Parameters, May 3, 2007															
2																				
3	Name	Count 2 RTML	Type	Int.Str.	MaxG,B	Lefm,	Xgap	YGap	Bpole,	Iw/pole,A	I,A	Wc	Lcu,	qcu,m	Vcu,m3	mcu/mag,t	Mcu,tons	Rw,Ohm	U,V	P,W
4	DC Quadrupoles																			
5	QRTML1	16	Q20L100	0.400	4.000	0.1	0.02	0.02	0.040	1.67E+02	2	84	96	1	0.0001	0.0009	0.01	1.93	3.9	8
6	QRTML2	1422	Q20L200	17.520	87.600	0.2	0.02	0.02	0.876	3.66E+03	20	183	387	10	0.0039	0.0344	48.94	0.77	15.5	309
7	QRTML3	8	Q20L400	6.650	16.625	0.4	0.02	0.02	0.166	6.95E+02	20	35	140	10	0.0014	0.0125	0.10	0.28	5.6	112
8	QRTML4	44	Q20L800	13.300	16.625	0.8	0.02	0.02	0.166	6.95E+02	20	35	276	10	0.0028	0.0245	1.08	0.55	11.0	220
9	QRTML5	36	Q60L200	3.714	18.570	0.2	0.06	0.06	0.557	6.99E+03	200	35	87	50	0.0044	0.0388	1.40	0.03	7.0	1395
10	SC Quadrupoles																			
11	QRTML6	36	QSC80L200	2.430	12.150	0.2	0.08	0.08	0.486	8.13E+03	50	163	SC	SC	SC	SC	SC	SC	SC	SC
12	DC Dipoles																			
13	DRTML1	32	D25L400	0.028	0.070	0.4	0.03	0.03	0.070	7.31E+02	50	15	16	12.5	0.0002	0.0018	0.06	0.03	1.3	63
14	DRTML2	128	D25L900V1	1.060	1.178	0.9	0.03	0.03	1.178	1.23E+04	50	246	561	12.5	0.0070	0.0624	7.99	0.90	44.9	2245
15	DRTML3	144	D25L900V2	0.904	1.004	0.9	0.4	0.03	1.004	1.05E+04	50	210	668	12.5	0.0083	0.0743	10.69	1.07	53.4	2670
16	DRTML4	144	D25L900V3	0.650	0.722	0.9	0.1	0.03	0.722	7.55E+03	50	151	371	12.5	0.0046	0.0413	5.95	0.59	29.7	1485
17	DRTML5	8	D25L1600	0.625	0.391	1.6	0.03	0.03	0.391	4.08E+03	50	82	323	12.5	0.0040	0.0360	0.29	0.52	25.9	1293
18	DRTML6	12	D25L1800	1.400	0.778	1.8	0.03	0.03	0.778	8.13E+03	50	163	722	12.5	0.0090	0.0803	0.96	1.15	57.7	2887
19	DRTML7	56	D25L1900	1.795	0.945	1.9	0.03	0.03	0.945	9.87E+03	50	271	1528	12.5	0.0191	0.1699	9.52	2.44	122.2	6110
20	DRTML8	180	D25L2300	1.823	0.793	2.3	0.03	0.03	0.793	8.28E+03	50	271	1267	12.5	0.0158	0.1410	25.38	2.03	101.4	5069
21																				
22	DC RT Correctors																			
23	DCRTML1	2248	D20L50	0.053	1.050	0.05	0.02	0.02	1.050	8.78E+03	5	1756	379	2.5	0.0009	0.0084	18.97	3.03	15.2	76
24																				
25	DC SC Correctors																			
26	DCRTML2	54	DSC80L200	0.0073	0.037	0.2	0.08	0.08	0.037	1.22E+03	100	12	11	SC	SC	SC	SC	SC	SC	SC
27																				
28	SC Solenoids																			
29	SLRTML1	8	SLSC20L260	13.099	4.999	2.62	0.02	0.02	4.999	4.02E+06	###	1005	221	SC	SC	SC	SC	SC	SC	SC
30																				
31	Total	4576														Total Cu,to	131.3			
32																				

RTML Magnet Changes

The following changes have been proposed by the Magnets TS group and approved by the RTML AS group.

Turnaround corrector quads (CQTURNn and SQTURNn magnets) will be changed to a 6 cm full aperture (current value is 5 cm).

Extraction line quad QDBCDL3 will be changed to a 6 cm full aperture (current value is 3 cm).

Spin rotator solenoids will be changed to 2.62 m effective length (current value is 4.16 m).

Cryomodule quads will be changed to 0.3 m effective length (current value is 0.666 m effective length).

EDR Magnet Deliverables

1. Design each magnet style:

- Magnetic design (2D and if need 3D magnetic field simulations to confirm specified field quality and magnet performance;
- Pole profile and geometry optimization for better integrated field quality;
- Mechanical and thermal analysis;
- Magnet documentation.

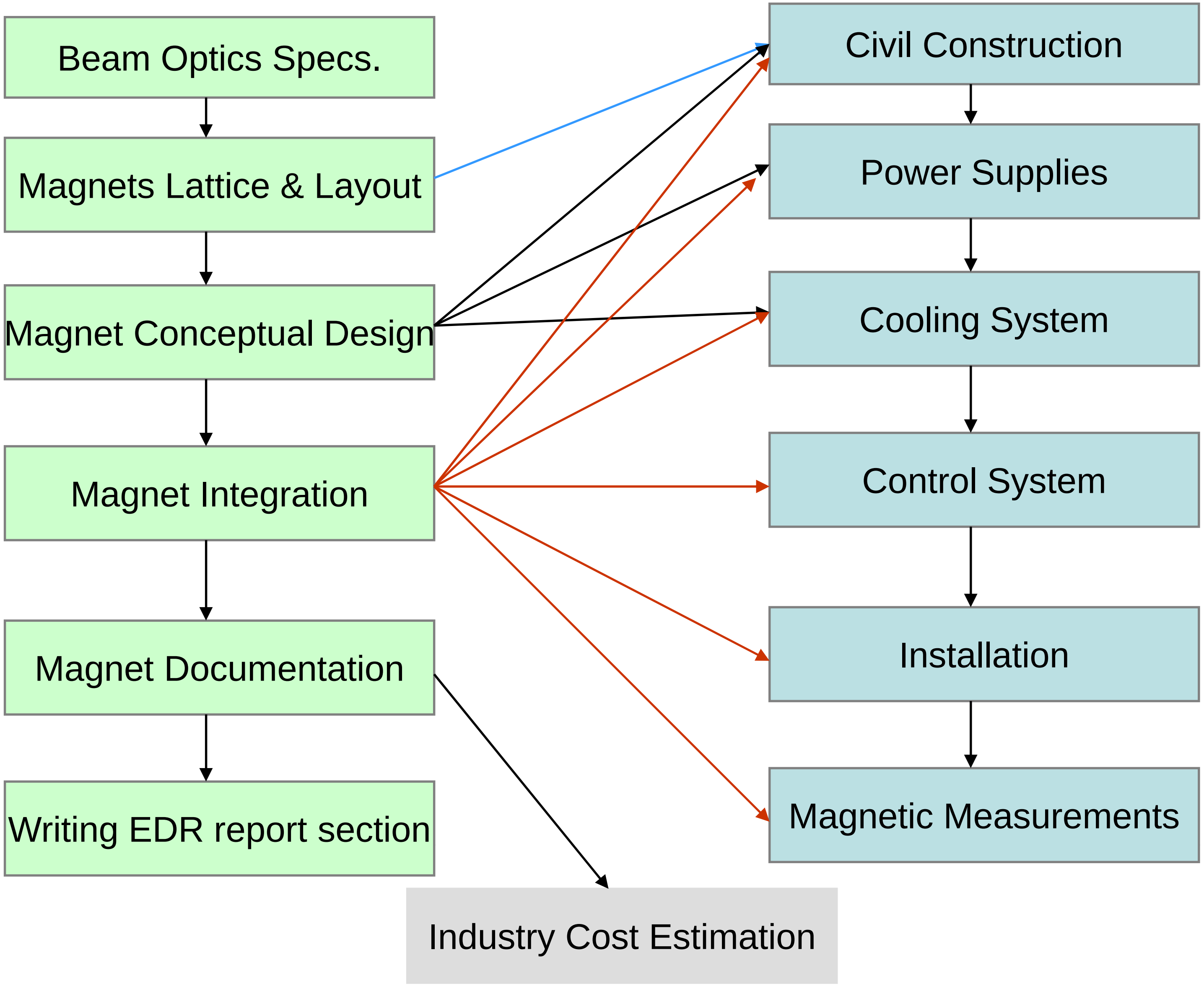
2. Magnet documentation package should include at least:

- Magnet specification with all needed parameters;
- Results of magnetic field analysis and also mechanical and thermal calculations.
- Magnet drawings with at least cross-sections and views transverse and longitudinal with all connections to the power, water, instrumentation and corresponding schematics;
- Description of all used materials: iron, copper, insulation, probes, cables, etc…
- Description of magnet manufacturing technology: winding coil technique, epoxy impregnation, curing, stamping laminations, yoke and magnet assembly, etc…
- Magnet support structure general views with adjusting mechanisms
- Drawing of magnet mounting in the tunnel.

EDR Magnet Design and Integration Process

1. Magnet design should be made by professionals only.
2. The time depends on the experience of design engineer and supporting team. Only institutions with accelerator magnet design, building and testing experience should participate in the bid.
3. Designers should use the general magnet specification document as guidance for magnet design. This document should describe in general way the magnet technology which must be used.
4. The magnet design and integration should include several steps:
    1. Magnet conceptual design.
    2. Review magnet parameters and integration with power supply, cooling, vacuum, instrumentation, control systems and civil construction.
    3. Magnet optimization to optimize performance, cost, technology, mounting, installation, etc.
    4. Review of optimized system including matching to other sub-systems.
    5. Preparing pre-fabrication drawings and documentation.

EDR Magnet Design Information Flow



Beam Optics Specs.

Magnets Lattice & Layout

Magnet Conceptual Design

Magnet Integration

Magnet Documentation

Writing EDR report section

Civil Construction

Power Supplies

Cooling System

Control System

Installation

Magnetic Measurements

Industry Cost Estimation

Magnet Design Issues

1. The design process and information flow, data exchange between different areas, regions, institutions, teams, specialists. We should expect large fraction of time will be waiting additional information, technical decisions, changes in specs, etc…
2. Integration with other sub-systems and making technical decisions for all areas simultaneously on the same issue and problem.
3. Find professionals for magnet design and integration with needed experience.
4. Converting R&D projects into useful results for EDR.
5. Wasting large fraction of specialists time for meetings, reports, reviews, travels with corresponding low impact on EDR progress.
6. Any change in lattice or general magnet parameters will cause magnet redesign and corresponding design time increase.
7. The late start of EDR writing.
8. Industry cost estimation for different regions and firm ranks.

RTML – Priorities for Detailed Design

- **Priorities for detailed design effort need to be established - key magnets: complexity, cost, quantity (and/or all of the above)**
  - **Detailed design & cost estimate**
  - **Optimization of parameters, e.g. peak field vs. integral required**
  - **Conventional vs. superconducting**
  - **FMEA/Reliability**
- **Candidates**
  - **Large solenoids in Spin Rotator section**
    - **Superconducting devices – cost & complexity**
    - **Individual cryostats – significant design task**
    - **Field uniformity and axis alignment – determine detailed requirements**
  - **SC quadrupoles in rf cryomodules**
    - **5-15 GeV beams ⇒ decrease in strength (via length change)**
  - **Transfer line quadrupoles and steering dipoles**
    - **Large quantities – requirements, cost**
  - **Kickers**
    - **RTML specific designs**

Detailed Design Labor Estimates

- The engineering and designer labor hours for detailed design of magnets has been estimated by the Magnet Systems group
  - Estimates are based on magnet engineering experience
  - Uncertainties include the usual: changes in requirements, programmatic changes, lack of dedicated resources, etc.
  - Units are FTE's

Estimated Magnet Design Effort		
Design	**Engr/Phys**	**Designer**
Moderate Conventional Magnet	0.25	0.65
Complex Conventional Magnet	0.40	1.20
Moderate SC Magnet	0.50	1.25
Complex SC Magnet	1.00	2.20
Cryostat	0.50	1.50

- FY08 budgets do not appear to support any significant magnet engineering effort (for detailed design)

Detailed Design ⇨ Reliability/FMEA

- Magnet reliability is a major concern
  - MTBT assigned for magnets in the range 10 – 20×10^6 hrs
  - Reliability must be ‘built in’ – part of the design process – and addressed early in the project
- FMEA – Failure Modes and Effect Analysis - is a structured, qualitative approach to understanding
  - which components in a system are most likely to fail
  - what the effects of the failure will be
  - the root causes of the failure
  - when in the component’s lifetime it fails

  (Note: FMEA was developed by the US military in 1960s - US MIL-STD-1629)
- FMEA need to be carried out on specific magnet ***detailed*** designs, representative of the magnet spectrum
  - Conventional, H_20 cooled, medium complexity
  - Superconducting magnet, e.g. quad in cryomodule
  - Conventional, air-cooled, simple design
  - Specialty or critical magnets, e.g. kickers
- This is an important ‘up front’ engineering task and cannot be left to the end

Detailed Design ⇨ Integration Issues

- ***EDR Magnets – ‘Interface/Integration’ Topics***
  - **Vacuum chamber (aka ‘beam pipe’) treatments**
    - Magnets must be taken apart (after installation) for insertion of beam pipe
    - Generic or magnet specific tooling will be needed
    - Impact on design, alignment, field quality, etc. must be studied
    - Bake-out questions – impact on magnets
  - **Power Systems**
    - Current, voltage, etc.
    - Review of stringing rules
    - Cable sizing and reliability
  - **Coordination with Technical and Global Systems**
    - **AC Power** – ‘treaties’ to be negotiated w/ Conv. Systems – Power
      - Define ‘boundaries’, responsibilities, etc.
    - **LCW system** – ‘treaties’ to be negotiated w/ Conv. Systems – LCW
      - Define ‘boundaries’, requirements, responsibilities, standards, etc.
    - **Controls interfaces** – ‘treaties’ to be negotiated w/ Controls Group
      - Define ‘boundaries’, requirements, responsibilities, etc.
    - **Installation** – ‘treaties’ to be negotiated w/Installation Group
      - Define ‘boundaries’, responsibilities, etc.
- **How does this get done?**

EDR – Definition, Schedule, and Resources

- **EDR – time scale FY07-FY09**
  - **FY2007 is over (funds are gone; magnet design not begun)**
  - **FY2008 has very limited resources for “low priority” items like magnets…**
  - **FY2009 appears to have some additional resources for magnet detailed design (mostly rumor…)**
  - **The conclusion is that there will not be a significant number of magnet styles with detailed designs by FY2010**
    - **No ability (or resources) to make a significant improvement in the cost estimate**
    - **Detailed beam line layouts will not exist**
      - **No ‘reality checks’ on completeness, access, interferences, etc**
    - **Not ready to begin construction**
  - **Compresses all of detailed design into the ‘pre-production’ and early project phases**
    - **Pile-up of work on magnet designers, draftspersons, etc.**
    - **Potential schedule impact on vendors and machine installation**
- **Ready for approval process in FY2010 (?)**
  - **Not a realistic schedule w/res to ~130 magnet designs**

RTML – What is Missing Here?

- **Kickers and Pulsed Magnets**
  - **R&D on fast pulsers is centered in DR effort**
  - **Separate effort for RTML?**
    - **Not efficient use of scarce resources**
    - **Some area specific issues need to be resolved**
  - **Is there a mechanism in the EDR approach to find a solution across Area System boundaries?**
- **More general concerns across Area Systems**
  - ***Common Design Standards***
    - ***Core - steel specifications, solid vs. laminations***
    - ***Conductor - Cu standard sizes, length requirements (i.e., no internal joints) I-V tradeoffs***
    - ***LCW - pressure drops, flow rates, temperature rise, fittings, hoses, etc.***
  - ***Cost Estimation Standards***
  - ***<u>Measurement & test</u>***
  - ***"Global' Reliability/Maintainability Studies***
    - ***Materials/components***
    - ***Processes***
    - ***Operating regimes & environments***

Summary

- All RTML magnets are feasible for design and fabrication.
- Total number of magnets 4576.
- Number of magnet styles: Dipoles- 6, Quadrupoles – 4 plus 1 – superconducting, Correctors – 2 plus 1 superconducting, 1 superconducting solenoid, plus septums, bumps and kickers.
- Time frame for the magnet design depends on many factors (region, firm, institution, salary range, experience, supporting structure, etc.) and better use bidding process to resolve this issue.
- Magnets for R&D and prototyping: 1- conventional dipole, 1- conventional quadrupole, 1- corrector, 1- superconducting quadrupole package including correctors, 1- superconducting solenoid 0.5 m model.
- Goals for R&D: prove chosen magnet technology, reliability, investigate magnetic center stability in quadrupoles at BBA, hysteresis effects in dipoles, prove the chosen magnetic measurement technique. Investigate coupling effects between main magnet and correctors. Investigate the magnets long term behavior.