Femtosource Internal Review
Preliminary Magnet Designs
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December 7, 2001

INTRODUCTION

- Magnet designs are reviewed.
    - Detail designs for each of the magnets are summarized in separate documents.

Requirements

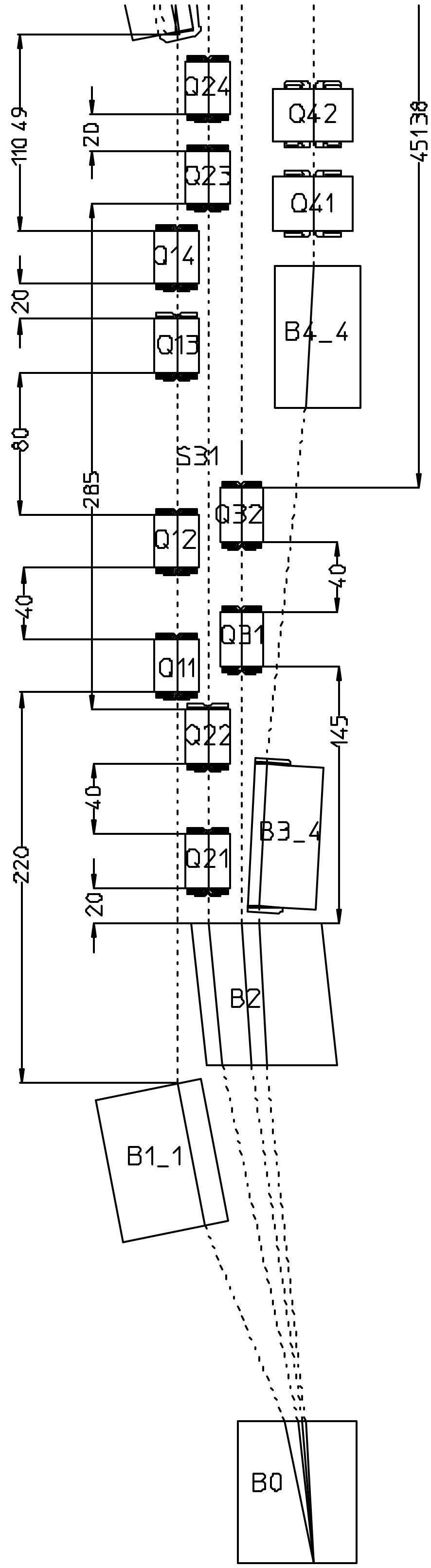
- The accelerator project includes four electron rings with beam energies approximately 0.7, 1.3, 1.9 and 2.5 GeV.
- All four beams are accelerated through the same linac.
    - Different energy beams are separated transversely before they orbit through their rings.
- The most demanding magnet designs are those in the separator section where the spaces between adjacent beams are small.
    - Results in septum styled dipoles and quadrupoles.
- The leakage field from the septum magnets to the adjacent beamlines must also be quantified and reduced.

Dynamic Range

- Fields and gradients of the various magnet types are modest.
- An additional requirement is to design the magnets for future upgrade to 1.5 times the nominal operating energies.
    - 150% dynamic range is large compared to design demands for other projects.
        - ALS magnet were designed for 1.5 GeV with capability of operating at 1.8 GeV, a 20% margin.
        - The PEPII LER and SPEAR3 magnets designs were required to have a 10% margin for future energy upgrade.
- In addition to having to deal with pole and yoke saturation effects, the 150% field margin represents a >225% power increase with similar demands on the cooling circuits.
- Operation at 150% of the design energy required a more complete and detailed magnet design than the “generic” geometries used in the usual zero order conceptual design.
- The designs reviewed in this document more closely resemble engineering designs than conceptual designs.

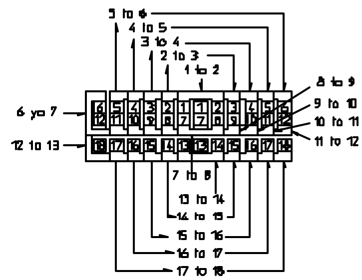
Field Quality

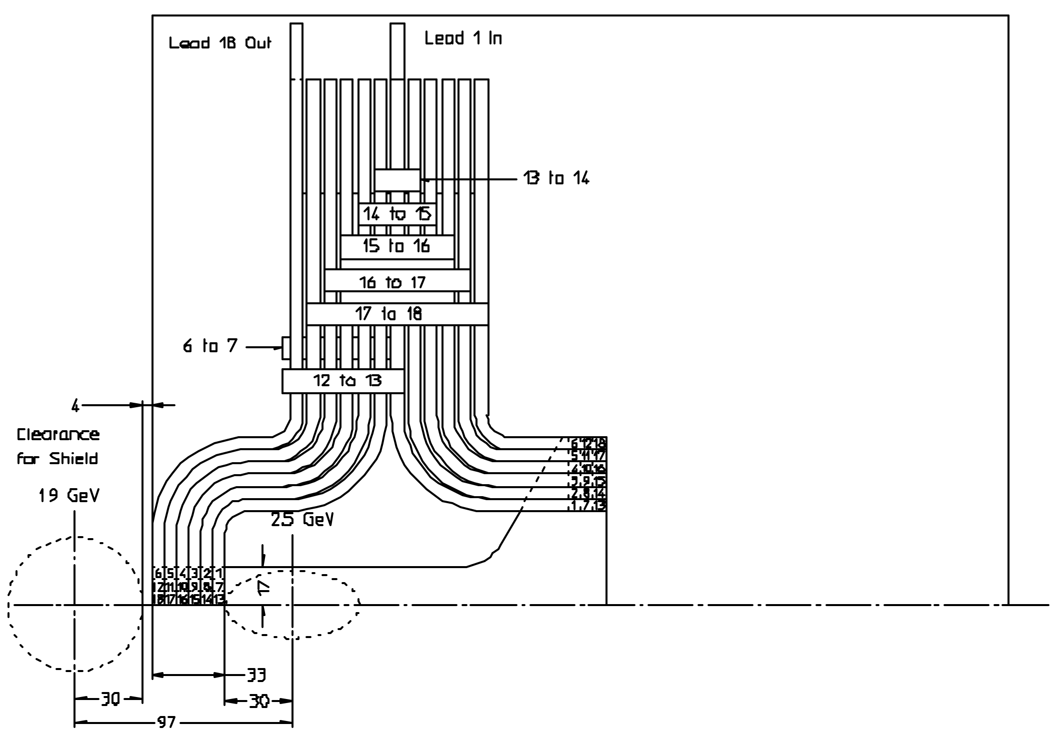
- The field quality requirements were not specifically spelled out for each magnet type.
- The field quality required for magnets employed in the typical storage ring were used as “achievable” goals (existence proof).
    - This should be adequate since the stringent field quality requirements for rings with multi-hour beam lifetimes is typically more demanding than for most other accelerators.


Q24
Q42
Q23
Q41
Q14
B4_4
Q13
S31
Q32
Q12
Q31
Q11
Q22
B3_4
Q21
B2
B1_1
B0
110 49
20
45138
20
80
285
40
40
145
40
220
20

B3_4 Septum Dipole

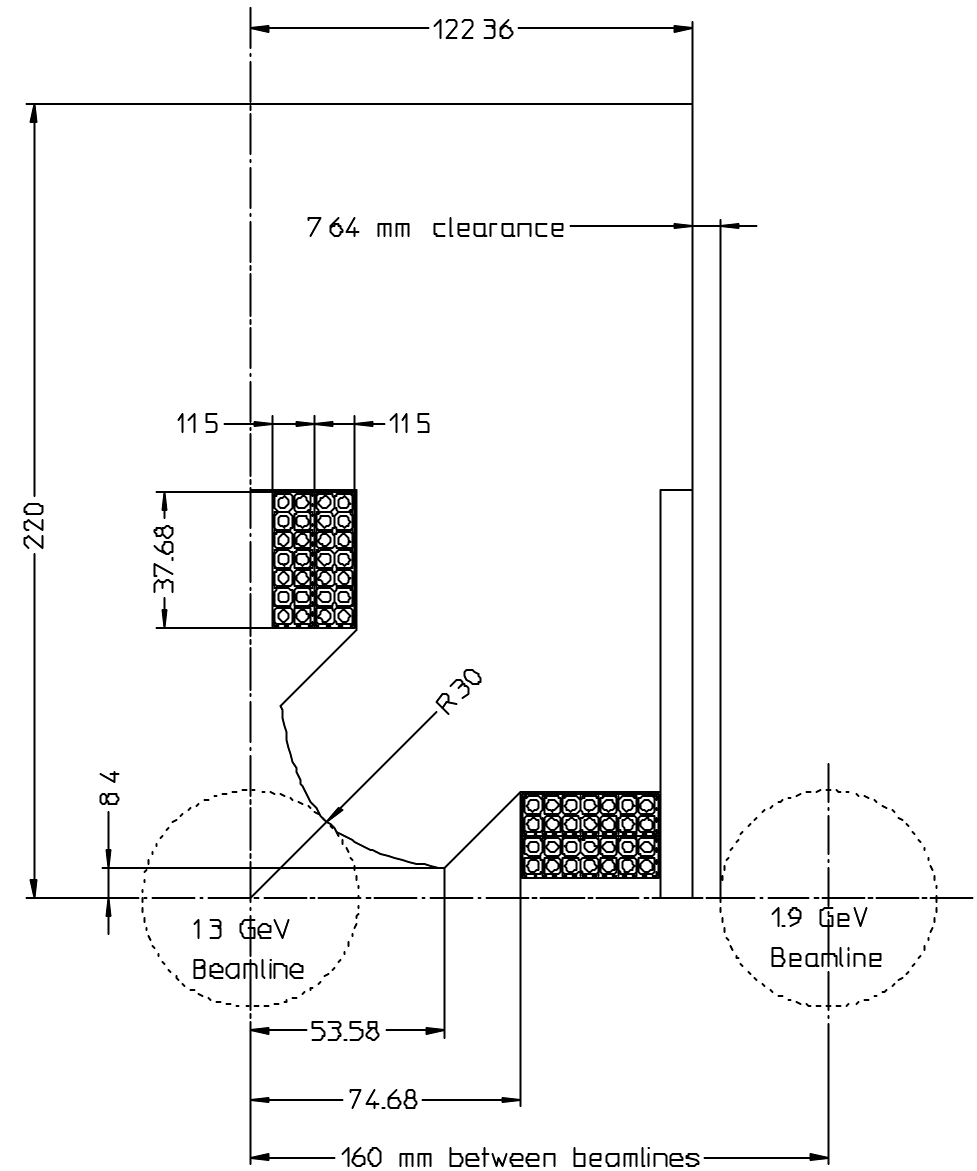
- The B3_4 septum dipole is the most demanding of the magnets.
- The limited space between the 1.9 and 2.5 GeV beamlines required a high current density septum.
- At 1.5 x the nominal energy, the water circuit topology requires one water circuit per turn.
- Detiled POISSON calculations were performed to evaluate both the field uniformity in the gap as well as the leakage field in the adjacent beamline with an iron shield inserted in the narrow 4 mm space between the magnet and the 1.9 GeV beamline.





Septum Quadrupole

- The septum quadrupole uses a "figure 8" design.
- The 7.64 mm space between the edge of the magnet and the adjacent beamline will be utilized for magnetic shielding, although the narrow vertical leg provides some shielding.



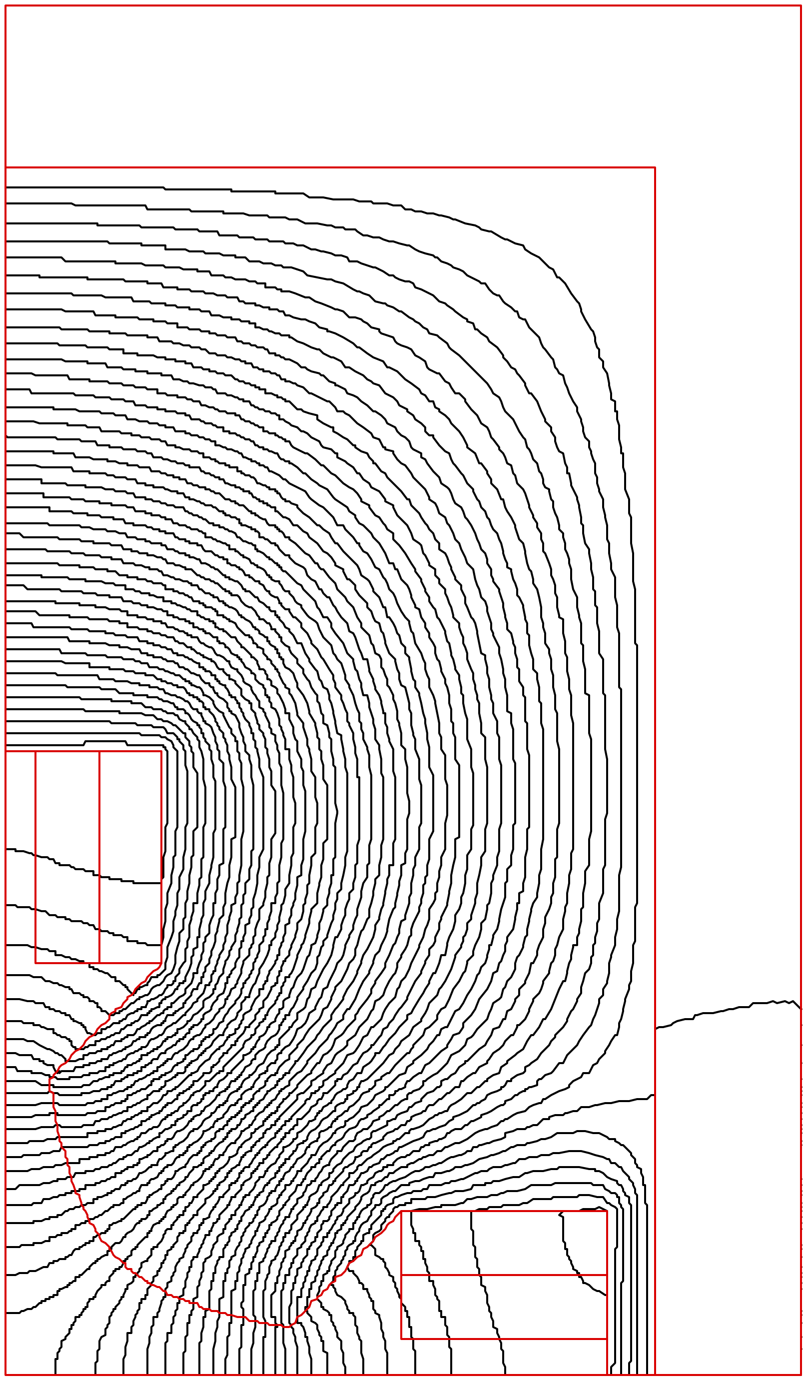
- Since the magnet requirements vary widely, two magnet variations are recommended.

Magnet	G (T/m)	1.5G (T/m)	N	R (Ω)	I (Amps)	V (V)	P (kW)	Pat1.5G (kW)
Q31	7.8466	11.7699	28	0.188	100.352	18.866	1.893	4.260
Q32	-10.6616	-15.9923	28	0.188	-136.353	-25.634	3.495	7.864
Q21	6.7237	10.0855	28	0.188	85.991	16.166	1.390	3.128
Q22	-9.6647	-14.4971	28	0.188	-123.605	-23.238	2.872	6.463
Q23	9.9327	14.8990	28	0.188	127.031	23.882	3.034	6.826
Q24	-13.8175	-20.7263	28	0.188	-176.716	-33.223	5.871	13.210
Q11	4.0701	6.1052	14	0.094	104.107	9.786	1.019	2.292
Q12	-7.5900	-11.3850	28	0.188	-97.071	-18.249	1.771	3.986
Q13	-0.5361	-0.8041	14	0.094	-13.712	-1.289	0.018	0.040
Q14	4.0855	6.1283	14	0.094	104.501	9.823	1.027	2.310

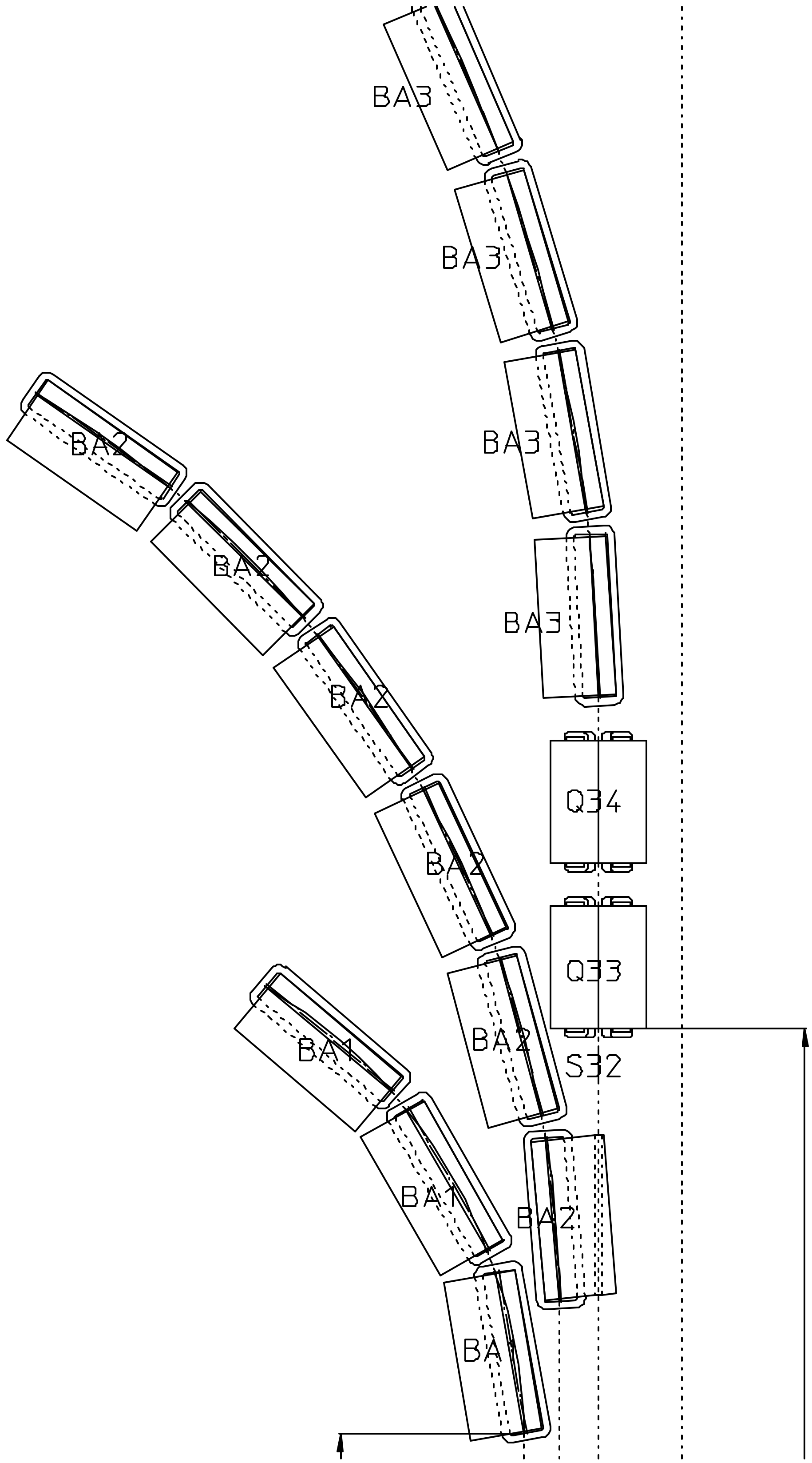
- For two magnets of each type.

$$\sum Power_{@G} = 44.8kW$$

$$\sum Power_{@1.5G} = 100.8kW$$



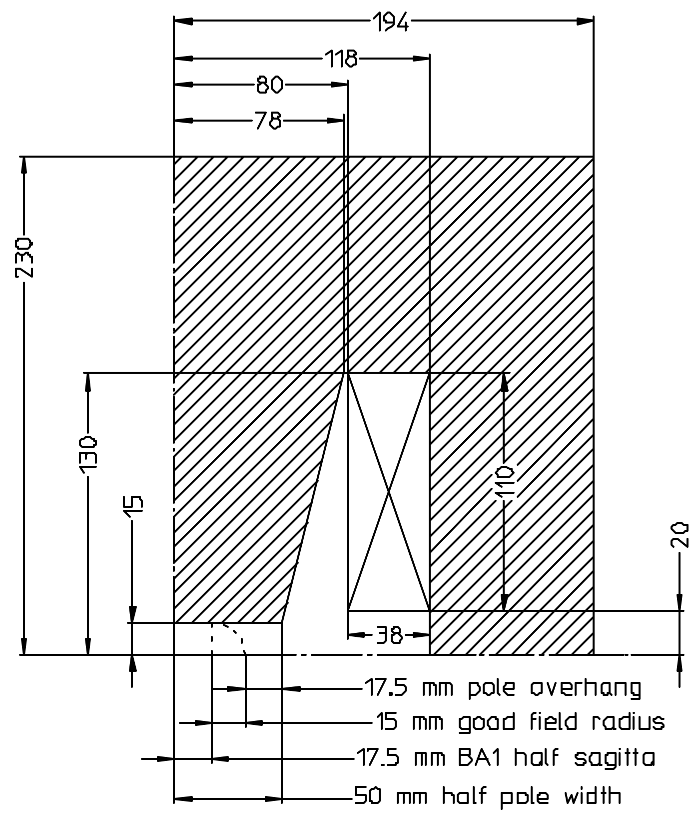
Main Ring Bends



- The longitudinal and transverse spatial constraints were factors affecting the magnet design.
    - The space constraints resulted in a "tall" coil package and a narrow pole.
- Another constraint was the required dynamic range for the magnet.
    - The field uniformity needed to be maintained from <1 T to >1.5 T.

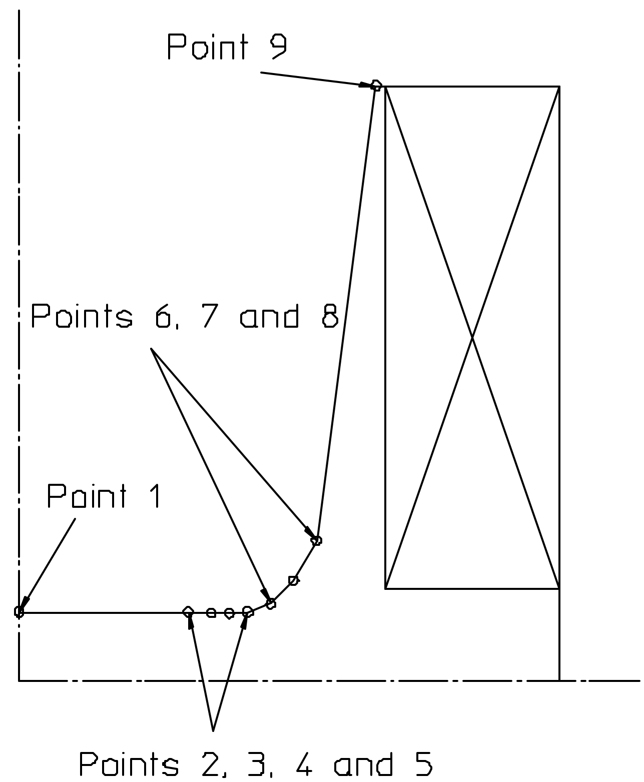
Baseline Geometry

- The baseline geometry was constrained by the 17.5 mm half sagitta for the softest (0.7 GeV) beam, the 15 mm half beam size plus a reasonable pole overhang to assure a good field quality.
- The coil shape was determined by a reasonable current density (to minimize power consumption) and the longitudinal space between adjacent magnets.
    - The pole edge angle was fairly steep.



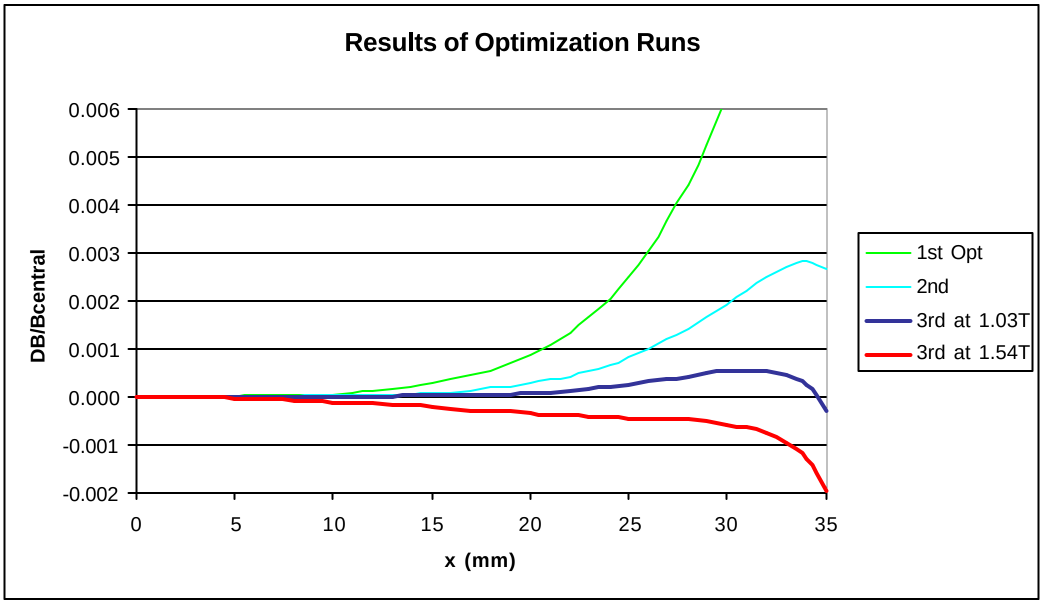
Optimized Pole

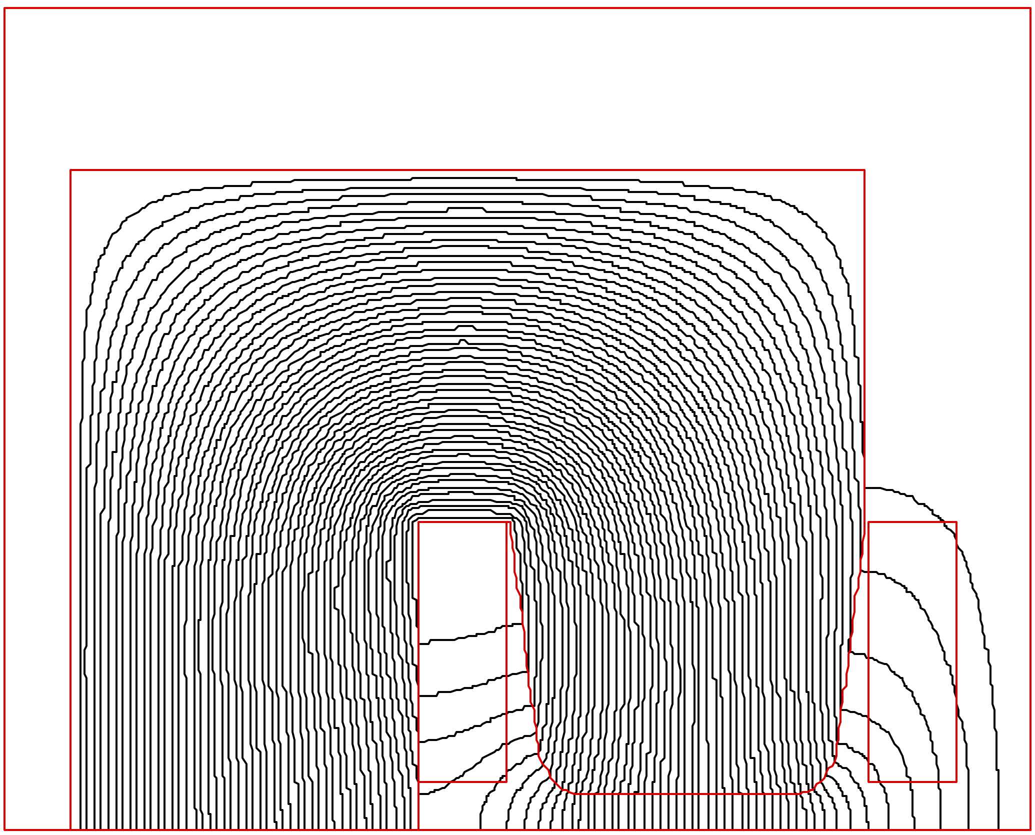
- The pole corner was "softened" to maintain field uniformity throughout the full range of excitation.
    - A sharp pole corner tends to "disappear" as it saturates at high field.
- Amplitudes of selected points on the pole were varied until a good field uniformity was achieved at both low and high excitations.



Points	x (mm)	y (mm)
1	0	15
2	37	15
3	42	14.7
4	46	14.6
5	50	15
6	55	16.82
7	60	21.82
8	65	30.48
9	78	130

Results of Optimization Runs



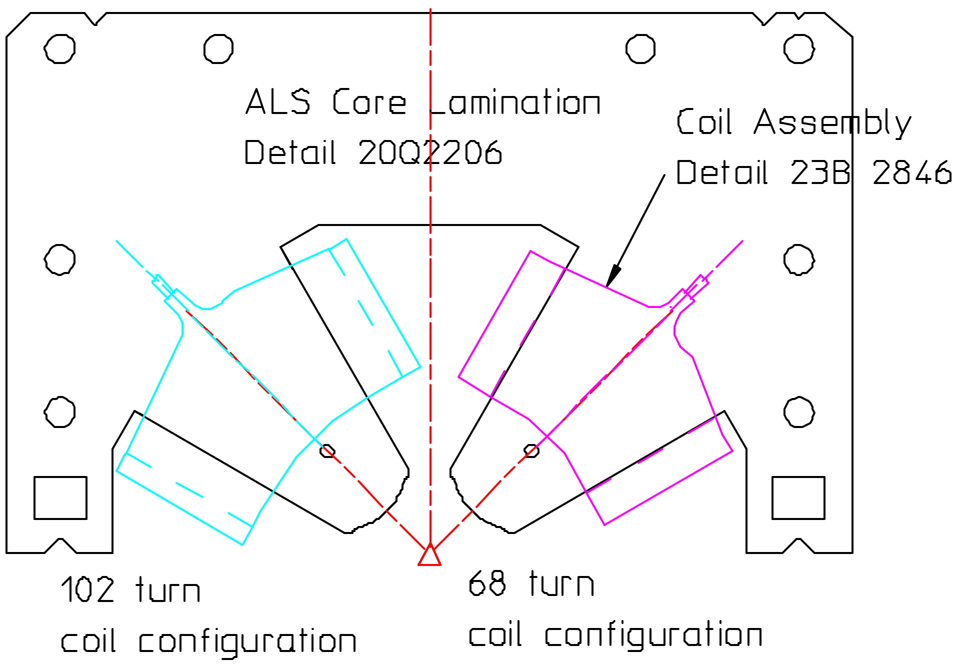


Power Supply Requirements

NAME	Number	H (T)	Current Amps	Mag. V (V)	Mag. P (kW)	P at 1.5x (kW)	Total P (kW)	Total P at 1.5x (kW)
BA1	18	1.0426	259.28	20.43	5.30	11.92	95.35	214.54
BA2	36	0.9594	238.58	18.80	4.49	10.09	161.47	363.31
BA3	54	0.9310	231.51	18.24	4.22	9.50	228.07	513.15
BA4	60	0.9899	246.17	19.40	4.78	10.74	286.52	644.68
						Total	771kW	1736kW

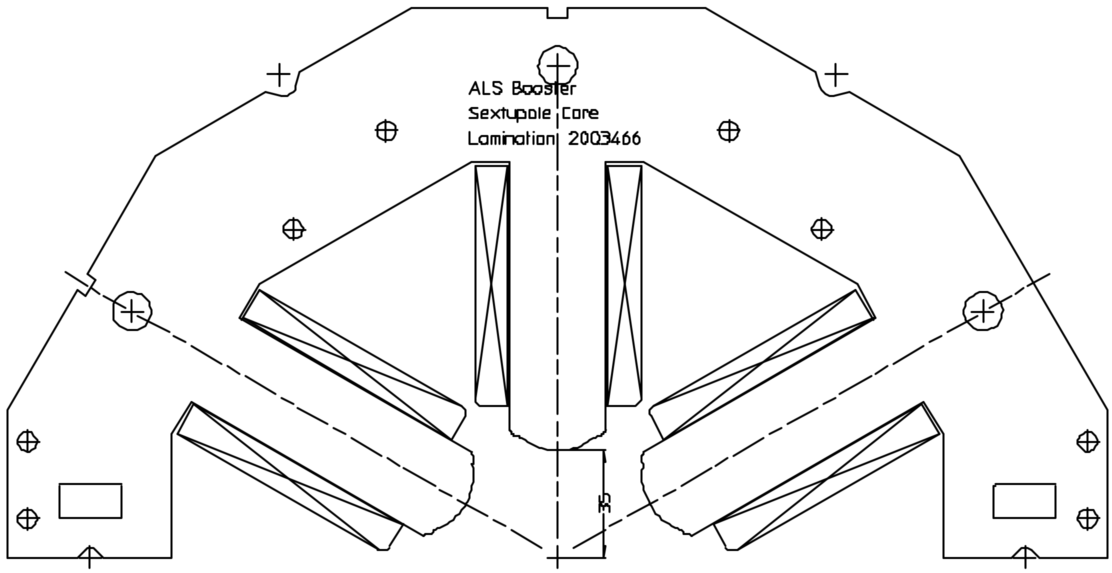
Main Ring Quadrupoles

- The yoke design for the main ring quadrupoles are patterned after the ALS booster and booster to storage ring quadrupoles.
  - o It is anticipated that the same die set used to stamp the lamination for these magnets can be employed.
- The coil design is patterned after the storage ring quadrupole coils, using small conductors so that low current power supplies can be employed.

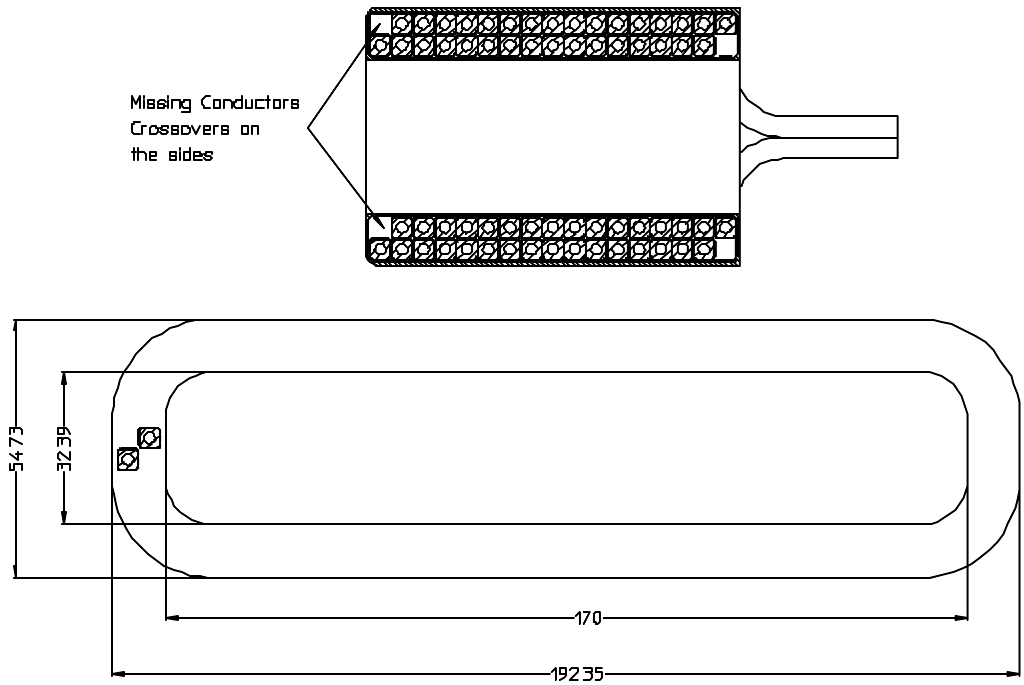


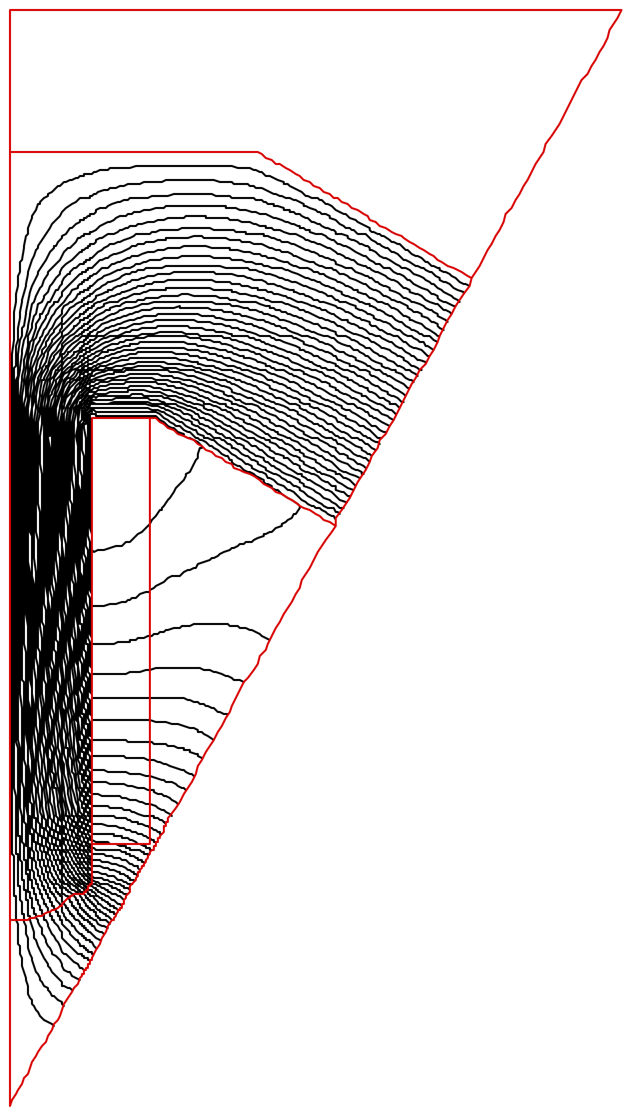
NAME	#	#	G	N	Cur	1.5xI	Res	Power	P	Ptot	Ptot at
									@1.5G		@1.5G
magnet	Short	Long	T/m	(turns)	(Amps)	(Amps)	(Ohms)	(kW)	(kW)	(kW)	(kW)
Q41	2		9.408	68	58.14	87.21	0.3832	1.30	2.91	2.59	5.83
Q42	2		-8.967	68	-55.42	-83.13	0.3832	1.18	2.65	2.35	5.30
Q43	2		2.844	68	17.57	26.36	0.3832	0.12	0.27	0.24	0.53
Q44	2		-2.291	68	-14.16	-21.24	0.3832	0.08	0.17	0.15	0.35
QA41		4	9.294	68	57.44	86.16	0.6328	2.09	4.70	8.35	18.79
QA42		4	-9.221	68	-56.99	-85.48	0.6328	2.06	4.62	8.22	18.50
QA43		4	8.304	68	51.32	76.99	0.6328	1.67	3.75	6.67	15.00
QM1		4	-10.811	68	-66.82	-100.23	0.6328	2.83	6.36	11.30	25.43
QM2		4	7.368	68	45.54	68.30	0.6328	1.31	2.95	5.25	11.81
QM3		4	0.000	68	0.00	0.00	0.6328	0.00	0.00	0.00	0.00
QM4		4	0.000	68	0.00	0.00	0.6328	0.00	0.00	0.00	0.00
QM5		4	5.893	68	36.42	54.63	0.6328	0.84	1.89	3.36	7.55
QM6		4	-8.330	68	-51.48	-77.22	0.6328	1.68	3.77	6.71	15.09
QM7		4	-5.870	68	-36.28	-54.42	0.6328	0.83	1.87	3.33	7.50
QM8		4	14.622	102	60.25	90.37	0.9796	3.56	8.00	14.22	32.00
QM9		4	-10.439	68	-64.52	-96.78	0.6328	2.63	5.93	10.54	23.71
QM10		4	15.199	102	62.63	93.94	0.9796	3.84	8.64	15.37	34.58
QM11		4	-14.128	102	-58.21	-87.32	0.9796	3.32	7.47	13.28	29.88
QM12		4	9.311	68	57.55	86.32	0.6328	2.10	4.72	8.38	18.86
QU1		4	11.522	102	47.47	71.21	0.9796	2.21	4.97	8.83	19.87
QU2		4	-15.070	102	-62.09	-93.14	0.9796	3.78	8.50	15.11	33.99
QU3		4	13.147	102	54.17	81.26	0.9796	2.87	6.47	11.50	25.87
Q33		4	7.359	68	45.48	68.22	0.6328	1.31	2.94	5.24	11.78
Q34		4	-10.943	68	-67.63	-101.45	0.6328	2.89	6.51	11.58	26.05
QA31	4		16.422	102	67.66	101.49	0.6024	2.76	6.21	11.03	24.82
QA32	4		-16.934	102	-69.77	-104.66	0.6024	2.93	6.60	11.73	26.39
QA33	4		16.836	102	69.37	104.06	0.6024	2.90	6.52	11.60	26.09
QS31	2		10.669	68	65.94	98.91	0.3832	1.67	3.75	3.33	7.50
QS32	2		-9.513	68	-58.79	-88.19	0.3832	1.32	2.98	2.65	5.96
QS33	2		7.516	68	46.45	69.68	0.3832	0.83	1.86	1.65	3.72
QS34	2		-7.516	68	-46.45	-69.68	0.3832	0.83	1.86	1.65	3.72
QS35	2		7.516	68	46.45	69.68	0.3832	0.83	1.86	1.65	3.72
QS36	2		-7.516	68	-46.45	-69.68	0.3832	0.83	1.86	1.65	3.72
QA21	4		16.220	102	66.83	100.24	0.6024	2.69	6.05	10.76	24.21
QA22	4		-14.835	102	-61.12	-91.69	0.6024	2.25	5.06	9.00	20.26
QA23	4		15.227	102	62.74	94.11	0.6024	2.37	5.34	9.48	21.34
QS21	2		-1.295	68	-8.00	-12.01	0.3832	0.02	0.06	0.05	0.11
QS22	2		3.377	68	20.87	31.31	0.3832	0.17	0.38	0.33	0.75
QS23	2		-5.360	68	-33.13	-49.69	0.3832	0.42	0.95	0.84	1.89
QS24	2		5.360	68	33.13	49.69	0.3832	0.42	0.95	0.84	1.89
QS25	2		-5.360	68	-33.13	-49.69	0.3832	0.42	0.95	0.84	1.89
QS26	2		5.360	68	33.13	49.69	0.3832	0.42	0.95	0.84	1.89
QA11	4		11.102	68	68.62	102.93	0.3832	1.80	4.06	7.22	16.24
QA12	4		-8.318	68	-51.41	-77.11	0.3832	1.01	2.28	4.05	9.11
QA13	4		9.007	68	55.67	83.50	0.3832	1.19	2.67	4.75	10.69
QS11	2		5.993	68	37.04	55.56	0.3832	0.53	1.18	1.05	2.37
QS12	2		-5.447	68	-33.66	-50.49	0.3832	0.43	0.98	0.87	1.95
QS13	2		2.984	68	18.44	27.66	0.3832	0.13	0.29	0.26	0.59
QS14	2		-2.984	68	-18.44	-27.66	0.3832	0.13	0.29	0.26	0.59
QS15	2		2.984	68	18.44	27.66	0.3832	0.13	0.29	0.26	0.59
QS16	2		-2.984	68	-18.44	-27.66	0.3832	0.13	0.29	0.26	0.59
Total	**80**	**80**								**271**	**611**

Main Ring Sextupoles



- The sextupole core laminations use the same shape as that used for the ALS booster sextupoles.
- The 32 turn coils are wound using hollow conductor and are made tall and narrow to fit between adjacent poles.


Missing Conductors
Crossovers on
the sides
54 73
32 39
170
192 35



- The following table assumes an identical design for all the magnets. If the power at 1.5xB" is less that 0.2 kW (200 Watts), the power per coil is <30 Watts.
  - At this level, the coil will operate safely even if water cooling is eliminated and the coil is cooled by natural convection.

Magnet	No. Required	B"	Current	Voltage	Power @B"	Power @1.5xB"
		(T/m^2)	(Amps)	(Volts)	(kW)	(kW)
S11	2	66.148	11.755	1.716	0.0202	0.0454
S12	2	-111.984	-19.900	-2.905	0.0578	0.1301
S13	2	0.000	0.000	0.000	0.0000	0.0000
SA11	2	-182.056	-32.352	-4.723	0.1528	0.3438
SA12	2	142.486	25.320	3.697	0.0936	0.2106
SA13	2	7.554	1.342	0.196	0.0003	0.0006
SA14	2	0.000	0.000	0.000	0.0000	0.0000
SA15	2	-97.118	-17.258	-2.520	0.0435	0.0978
SA16	2	81.591	14.499	2.117	0.0307	0.0691
S22	2	-136.042	-24.175	-3.530	0.0853	0.1920
S23	2	0.000	0.000	0.000	0.0000	0.0000
SA21	2	-58.700	-10.431	-1.523	0.0159	0.0357
SA22	2	-8.279	-1.471	-0.215	0.0003	0.0007
SA23	2	-178.854	-31.783	-4.640	0.1475	0.3318
SA24	2	0.000	0.000	0.000	0.0000	0.0000
SA25	2	0.000	0.000	0.000	0.0000	0.0000
SA26	2	6.195	1.101	0.161	0.0002	0.0004
S31	2	0.000	0.000	0.000	0.0000	0.0000
S32	2	425.271	75.572	11.033	0.8338	1.8761
S33	2	-454.303	-80.731	-11.787	0.9515	2.1410
SA31	2	1.969	0.350	0.051	0.0000	0.0000
SA32	2	-27.118	-4.819	-0.704	0.0034	0.0076
SA33	2	-178.148	-31.657	-4.622	0.1463	0.3292
SA34	2	0.000	0.000	0.000	0.0000	0.0000
SA35	2	0.000	0.000	0.000	0.0000	0.0000
SA36	2	-130.250	-23.146	-3.379	0.0782	0.1760
S41	2	-467.951	-83.156	-12.141	1.0096	2.2716
SA41	2	-7.553	-1.342	-0.196	0.0003	0.0006
SA42	2	-5.656	-1.005	-0.147	0.0001	0.0003
SA43	2	-11.006	-1.956	-0.286	0.0006	0.0013
SA44	2	0.000	0.000	0.000	0.0000	0.0000
SA45	2	383.198	68.095	9.942	0.6770	1.5232
SA46	2	-104.192	-18.515	-2.703	0.0501	0.1126

- Assuming two magnets of each type;

$$Power_{@B"} = 8.8kW$$

$$\sum Power_{@1.5\times B"} = 19.8kW$$

Plans

- The time between the zeroth order design, the development of a Conceptual Design Document, numerous internal and external reviews to determine the feasibility as well as the final funding for a large accelerator project is typically many years. Thus, a fairly uncertain time scale exists for the development of engineering and mechanical designs for major accelerator components, such as magnets.
- Therefore, it is planned to gather the following files in a single folder.
    - Magnet design documents (Word files).
    - Supporting calculations (Excel files).
    - Text files used for the POISSON 2D magnetostatic calculations
    - CAD drawing database (ME10 files) for the magnet design figures.
- This folder will be burned onto CD's which can be kept until the project materializes.
    - If the lattice and therefore the magnet parameters change significantly, these documents can be used as templates for the future designs.

Summary and Conclusions

- The magnet system for the recirculating linac project employs, probably, the most mature of the accelerator technologies.
    - A few of the magnet inventory demand relatively sophisticated design and engineering.
    - Other designs can be extrapolated from existing (proven) designs.
- The spatial constraints as well as the need to design for a very large margin for future upgrades require the designs to be highly evolved and the design parameters to be narrowly defined.
- A list can be developed using the engineering parameters evolved in the designs and the physics specifications from the lattice designs. These parameters are valuable.
    - They identify infrastructure requirements (LCW cooling systems)
    - They identify specifications for power supplies and their distribution system.
- Because the engineering design for the main magnets is detailed,
    - a cost estimate and schedule for the magnet fabrication can be developed.
    - development of cost and schedule for power supplies and their distribution system is possible.
- Other tasks associated with the magnet systems must be clearly defined and their effort and costs included.
    - Prototype evaluation of several magnet designs.
        - Development of 3D end chamfers.
    - Magnet Measurements
    - Magnet fiducialization,
    - Installation and alignment.
- In addition, the magnet safety systems, such as interlocks and personnel safety systems, should not be ignored since they represent significant costs and design effort.