Engineering parameter list for the Study 2a front-end

R.C. Fernow & J.C. Gallardo
Brookhaven National Laboratory

1 February 2008

We gather together the parameters that define the front end of the Study 2a neutrino factory design. Tables of components have been extracted from the ICOOL simulation files[1] and are presented in a more "engineer friendly" manner.

1. Introduction

The Study 2a design for a neutrino factory front end was conceived by R. Palmer [1] as a lower cost alternative to the Study 2 front end [2]. The design was made possible by the development of adiabatic bunching and phase rotation by D. Neuffer [3]. Many of the details of the design were worked out during a year-long APS study of the physics of neutrinos [4]. Overall descriptions and performance characteristics of the front end are contained in a number of technical notes [5-7] and publications [8-10]. The Study 2a front end was adopted as the baseline for the International Scoping Study (ISS) of a common neutrino factory design [11]. In this report we gather together some relevant engineering details about the front end. Some of this information is also contained in an earlier private note [12].

We define the axial position z = 0 as the end of the target. Then it is useful to break up the front end into the axial regions indicated in Table 1.1.

Table 1.1 Front-end regions

region	length [m]	start [m]	end [m]
collection	12.2	0	12.2
decay	98.5	12.2	110.7
buncher	51.0	110.7	161.7
rotator	54.0	161.7	215.7
cooling	84.0	215.7	299.7

[1] The parameters listed here come from ICOOL input model F54d.

2. Target

Study 2a used a liquid mercury jet target. Some parameters of the target are given in Table 2.1.

Table 2.1 Target properties

material	liquid mercury
angle of Hg jet wrt solenoid axis	100 mrad
angle of proton beam wrt solenoid axis	67 mrad
jet velocity	20 m/s
jet diameter	1 cm
interaction diamond length	60 cm

3. Pion collection region

A system of solenoids nearby the target is used to collect the pions produced from the proton interactions with the mercury. The pion collection region extends from z = 0 to z = 12.2 m. The radius of the beam pipe grows from 7.8 cm to 30 cm in the collection region as shown in Table 3.1.

Table 3.1 Beam pipe taper

z [m]	r [m]
0 – 1	0.078 + 0.018 * z
1 – 12.2	0.101 + 0.0178 * (z - 1)

The magnetic field falls off in the collection region. The field is produced by the solenoid magnets listed in Table 3.2.

Table 3.2 Collection magnets

No.	type	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
1	SC	-1.252	0.683	0.64	0.64	52.87
2	Fe	-0.846	0.326	0.43	0.01	29.29
3	Fe	-0.726	0.206	0.15	0.01	46.36
4	Cu	-0.500	0.948	0.16	0.07	16.52
5	Cu	-0.500	1.320	0.24	0.10	19.69
6	Cu	-0.500	1.791	0.35	0.16	20.96
7	SC	-0.400	0.690	1.00	0.21	26.23
8	SC	0.310	0.640	0.80	0.21	52.95
9	SC	1.070	0.850	0.80	0.21	63.02
10	SC	1.940	0.880	0.80	0.15	47.09
11	SC	2.840	1.160	0.80	0.09	56.74
12	SC	4.100	0.470	0.673	0.07	45.97
13	SC	4.590	1.127	0.80	0.05	65.18
14	SC	5.803	1.070	0.74	0.05	44.00
15	SC	6.910	1.360	0.849	0.05	39.77
16	SC	8.500	0.990	1.00	0.05	45.69
17	SC	9.800	1.900	1.00	0.05	32.01
18	SC	12.180	0.470	1.00	0.10	42.96

There are three normal-conducting copper solenoids near the target. Magnets number 2 and 3 are solenoid approximations to iron plugs in front of the target. All other magnets in the front end are superconducting solenoids. In the table *z* is the beginning axial position of the coil, *L* is the axial length, *a* is the inner radius, *t* is the radial thickness, and *J* is the engineering current density.

4. Pion decay region

The pion decay region is a 98.5 m long section of empty solenoid channel. The beam pipe radius is 30 cm for the whole region. The magnetic lattice begins with the matching section given in Table 4.1.

Table 4.1 Matching magnets

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
19	13.00	0.36	0.43	0.10	12.63
20	13.50	0.36	0.43	0.10	16.74
21	14.00	0.36	0.43	0.10	19.42
22	14.50	0.36	0.43	0.10	19.06
23	15.00	0.36	0.43	0.10	18.84

In the table *z* is the beginning axial position of the coil. This is following by a uniformly spaced lattice of large radius solenoids given in Table 4.2. The magnetic lattice has a period of 50 cm.

Table 4.2 Large radius magnets

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
24-71	15.5-39.0	0.36	0.43	0.10	19.22

In the table *z* is the beginning axial position of the coil. Next comes another matching section given by Table 4.3.

Table 4.3 Matching magnets

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
72	39.50	0.360	0.43	0.10	18.76
73	39.96	0.355	0.45	0.10	20.39
74	40.45	0.364	0.377	0.10	18.67
75	40.96	0.389	0.352	0.10	19.16
76	41.50	0.360	0.32	0.10	18.91

In the table *z* is the beginning axial position of the coil. This is following by a uniformly spaced lattice of small radius solenoids given in Table 4.4.

Table 4.4 Small radius magnets

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
77-209	42.0-108.0	0.36	0.32	0.10	19.00

In the table *z* is the beginning axial position of the coil. The magnetic lattice has a period of 50 cm.

Next comes another matching section given by Table 4.5.

Table 4.5 Matching magnets

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
210	108.50	0.360	0.32	0.10	18.71
211	109.00	0.36	0.32	0.10	17.48
212	109.50	0.36	0.32	0.10	16.68
213	110.25	0.408	0.65	0.10	40.43
214	111.20	0.50	0.65	0.10	24.37

In the table *z* is the beginning axial position of the coil.This matching section extends into the start of the buncher region.

5. Buncher region

The buncher region extends from z = 110.7 m to 161.7 m. There is a uniform solenoid lattice in this region with properties given in Table 5.1.

Table 5.1 Buncher magnetic lattice

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
215-281	111.95-161.45	0.50	0.65	0.10	21.01

In the table *z* is the beginning axial position of the coil. The magnetic lattice has a period of 75 cm.

This region also contains a series of pillbox RF cavities. Each cavity is 50 cm long. The iris of each cavity is closed off on both sides with a 25 cm radius beryllium window. The cavity properties are given in Table 5.2.

Table 5.2 Buncher RF cavities

No.	z [m]	f [MHz]	G [MV/m]	r_{cav} [cm]	t [μm]
1	113.08	332.6	5	34.5	200
2	122.08	308.2	10	37.2	395
3	131.95	284.6	7	40.3	200
4	132.45	284.6	7		200
5	136.45	275.3	10	41.7	395
6	136.95	275.3	10		395
7	141.82	264.4	10	43.4	395
8	142.32	264.4	10		395
9	142.83	264.4	10		395
10	146.95	255.7	10	44.9	395
11	147.45	255.7	10		395
12	148.45	253.1	10	45.3	395
13	148.95	253.1	10		395
14	151.45	248.1	7	46.3	200
15	151.95	248.1	7		200
16	153.07	245.1	7	46.8	200
17	153.58	245.1	7		200
18	154.08	245.1	7		200
19	155.20	242.1	7	47.4	200
20	155.70	242.1	7		200
21	156.70	239.8	10	47.9	395
22	157.20	239.8	10		395
23	158.32	237.0	10	48.4	395
24	158.83	237.0	10		395
25	159.33	237.0	10		395
26	160.45	234.2	10	49.0	395
27	160.95	234.2	10		395

In the table z is the starting position of the cavity, r_{cav} is the inner radius of the pillbox cavity, and t is the thickness of the beryllium window.

6. Rotator region

The rotator region extends from z = 161.7 m to 215.7 m. There is a uniform solenoid lattice in this region with properties given in Table 6.1. The magnetic lattice has a period of 75 cm.

Table 6.1 Rotator magnetic lattice

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
282-350	162.20-213.20	0.50	0.65	0.10	21.01

In the table *z* is the beginning axial position of the coil. This region also contains a series of pillbox RF cavities. Each cavity is 50 cm long and has a gradient of 12.5 MV/m. The iris of each cavity is closed off on both sides with a tapered beryllium window. The thickness of the window is 750 μm out to a radius of 20 cm and 1500 μm for a radius of 20 to 25 cm. The cavity properties are given in Table 6.2.

Table 6.2 Rotator RF cavities

No.	z [m]	f [MHz]	r_{cav} [cm]
28	162.07	231.9	49.5
29	162.58	231.9	
30	163.08	231.9	
31	164.32	228.9	50.1
32	164.83	228.9	
33	165.33	228.9	
34	166.57	226.2	50.7
35	167.08	226.2	
36	167.58	226.2	
37	168.82	223.6	51.3
38	169.33	223.6	
39	169.83	223.6	
40	171.07	221.3	51.9
41	171.58	221.3	
42	172.08	221.3	
43	173.32	219.1	52.4
44	173.83	219.1	
45	174.33	219.1	
46	175.57	217.2	52.8
47	176.08	217.2	
48	176.58	217.2	
49	177.95	215.1	53.3
50	178.45	215.1	
51	178.95	215.1	
52	179.45	215.1	
53	180.95	212.9	53.9
54	181.45	212.9	
55	181.95	212.9	

56	182.45	212.9	
57	183.95	211.0	54.4
58	184.45	211.0	
59	184.95	211.0	
60	185.45	211.0	
61	186.82	209.4	54.8
62	187.33	209.4	
63	187.83	209.4	
64	189.32	207.9	55.2
65	189.82	207.9	
66	190.33	207.9	
67	190.83	207.9	
68	191.33	207.9	
69	193.19	206.1	55.7
70	193.70	206.1	
71	194.20	206.1	
72	194.70	206.1	
73	195.20	206.1	
74	195.71	206.1	
75	198.06	204.2	56.2
76	198.57	204.2	
77	199.07	204.2	
78	199.57	204.2	
79	200.08	204.2	
80	200.58	204.2	
81	201.08	204.2	
82	201.58	204.2	
83	202.09	204.2	
84	205.55	202.3	56.7
85	206.06	202.3	
86	206.56	202.3	
87	207.06	202.3	
88	207.57	202.3	
89	208.07	202.3	
90	208.57	202.3	
91	209.08	202.3	
92	209.58	202.3	
93	210.08	202.3	
94	210.58	202.3	
95	211.09	202.3	
96	211.59	202.3	
97	212.09	202.3	
98	212.60	202.3	
99	215.08	202.3	

7. Cooling region

The cooling region extends from z = 215.7 m to 299.7 m. There is a matching section between the rotator and cooling sections given in Table 7.1.

Table 7.1 Matching magnets

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
351	213.95	0.50	0.65	0.10	21.11
352	214.70	0.50	0.65	0.10	20.82
353	215.63	0.15	0.35	0.15	34.50
354	216.38	0.15	0.35	0.15	64.73
355	217.13	0.15	0.35	0.15	-107.11

In the table *z* is the beginning axial position of the coil.The remainder of the cooling region has a periodic solenoid lattice with alternating polarity. The coil parameters are given in Table 7.2.

Table 7.2 Cooling magnetic lattice

No.	z [m]	L [m]	a [m]	t [m]	J [A/mm^2]
356-464	217.88-298.88	0.15	0.35	0.15	±106.67

The channel has a period of 75 cm and starts with positive polarity. In the table *z* gives starting location of the coil.

This region also contains a series of pillbox RF cavities. Each cavity is 50 cm long and has a gradient of 15.25 MV/m. The window on each side of the cavity consists of three parts: 25 μm of beryllium, 1 cm of LiH, and 25 μm of beryllium[2]. The window radius is 25 cm. The pillbox radius is 57 cm. The cavity properties are given in Table 7.3.

Table 7.3 Cooler RF cavities

No.	z [m]
100 - 211	215.83 – 299.08

In the table *z* gives starting location of the cavity. The cavities are uniformly spaced with a period of 75 cm.

[2] Preliminary studies [6] of the thermal properties of the cavity window indicated that the beryllium layer facing the RF cavity may need to be ~300 μm thick.

The lithium hydride absorbers all have a radius of 25 cm. Their properties are summarized in Table 7.4.

Table 7.4 Cooler LiH absorbers

No.	z [m]	t [cm]
1	215.68	2
2 - 113	215.81 – 299.06	1
114 - 225	216.33 – 299.58	1

In the table *z* gives starting location of the absorber. The first absorber is used for energy correction going into the cooling channel. The other absorbers are uniformly spaced with a period of 75 cm.

8. Summary

Some overall properties of the Study 2a front end are listed in Table 8.1.

Table 8.1 Study 2a front end properties

Channel length	299.7 m
Number of normal conducting solenoids	3
Number of superconducting solenoids	459
Number of RF cavities	211
Number of LiH absorbers	225
Total peak voltage in buncher	116 MV
Total peak voltage in rotator	450 MV
Total peak voltage in cooler	854 MV
Total volume of LiH	35.5 L

Acknowledgements

We would like to thank everyone who worked on the Study 2a front end design.

References

[1] R. Palmer, Front end simulations, Muon Collaboration Meeting, Riverside CA, January 2004.

[2] Feasibility Study II of a muon based neutrino source, S. Ozaki et al (ed), BNL report 52623, June 2001.

[3] D. Neuffer, Exploration of the high-frequency buncher concept, Muon Collaboration technical note 269, February 2003.

[4] C. Albright et al, Neutrino factory and beta beam experiments and development, BNL report 72369, July 2004.

[5] R. Fernow et al, Front end design for neutrino factory Study 2a, Muon Collaboration technical note 296, August 2004.

[6] R. Fernow, Heating in the Study 2a absorber window, Muon Collaboration technical note 317, May 2005.

[7] R. Fernow & J.C. Gallardo, Examination of the US Study 2a neutrino factory front-end design, Muon Collaboration technical note 331, January 2006.

[8] R. Fernow et al, Study 2a neutrino-factory front-end design, Nuc. Phys. B (proc. Suppl.) 149:274-276, 2005.

[9] J. Gallardo et al, New and efficient neutrino factory front-end design, Proc. 2005 Part. Accel. Conf., Knoxville, TN, p. 2986-2988.

[10] J.S. Berg et al, Cost-effective design for a neutrino factory, Phys. Rev. ST-AB 9, 011001 (2006).

[11] M. Zisman, Summary report of the Accelerator Working Group, International Scoping Study of a Future Neutrino Facility and Superbeam Facility, March 2007.

[12] R. Fernow & J. Gallardo, Front End: magnetic channel and RF cavity parameters, 25 May 2004.