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Estimate of front-end magnetic requirements for Palmer's muon collider scenario

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We make a rough first estimate of the magnet requirements for the front end of a muon collider. We base the estimate on the muon collider scenario proposed by Bob Palmer. Approximately 4100 superconducting solenoids are needed for the front end in this scenario.

Introduction

Recently the question has been raised about the scale of magnet development required for a muon collider. Many of the superconducting magnets needed for the collider are used in the front end, which collects the particles produced at the target, reduces the emittance of the resulting beam, and creates muon bunches suitable for subsequent acceleration. One of the most detailed schemes for the front end of a muon collider was proposed by Bob Palmer [1,2]. We use the subsystems defined in this scenario to give a rough estimate for the magnet requirements. The scenario is shown in block diagram in Fig. 1

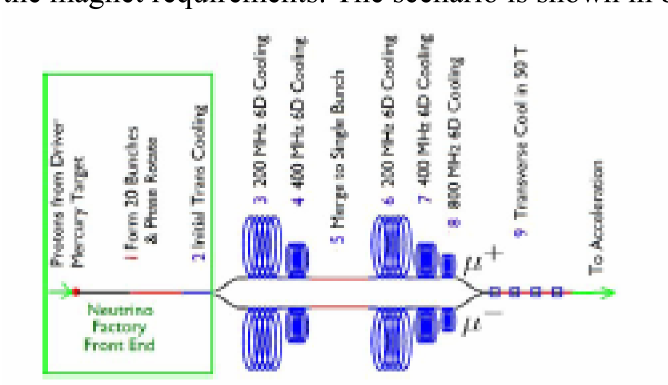

Figure 1. Possible layout for the front end of a muon collider [2]

It is obviously impossible to give a realistic description of front end magnet requirements at this time. There are currently three scenarios under active investigation. None of the scenarios has had more than preliminary simulation work done. The possibility of tapering the channels is under investigation and this could lead to modifications of the specified lattice parameters. The site layout of the subsystems has also not been determined, so it is impossible to know the length of necessary transfer lines. Partly for these reasons the collider 5-year ZDR plan does not call for a baseline design to be specified until 2011.

In addition there is great uncertainty at this time about the consequences of RF breakdown in magnetic fields. We will not be able to make trustworthy designs until this issue is resolved by the experimental program at the MTA. We believe that it is likely that all of our present lattice designs will need to be modified to take RF breakdown effects into account.

Another problem is that many of the front end subsystems will need to be joined using matching sections, none of which have been designed yet. For the magnet count in this report we have just assumed that all the required matching sections can be constructed using sets of six alternating solenoid magnets with freely adjustable parameters.

1. Precooler

The scenario begins with the Study 2a neutrino factory front end [3]. The collider only uses 50 m of the 80 m long transverse cooling channel in Study 2a. There are 419 superconducting solenoids and 3 normal conducting solenoids in the collider precooler. The parameters of these solenoids have been compiled in a technical note [4] and are not repeated here.

2. Beam separator

After some initial transverse cooling the positive and negative muons must be split into separate channels. This separator has not been designed yet. However, we have done previous charge separation designs using bent solenoids [5]. We assume we can match into the separator using alternating solenoids with parameters approximately like those given in the following table.

number	6
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	34
B_0 [T]	2

In the tables *d* is the cell length, *L* is the length of the coil, *a* is the inner radius of the coil, *t* is the radial thickness of the coil, J_e is the engineering current density, and B_0 is the peak on-axis field in the cell. The first bent solenoid needs an input radius around 30 cm. The solenoid then bends, for example, in the horizontal plane, causing the two charges to separate vertically. The exit of the magnet needs to be large enough to contain separate 30 cm radius channels for the two charges. At the exit of the bent solenoid we need ~30 m of transport to get the two beams far enough apart to allow, for example, parallel Guggenheim channels to follow. We assume the transport can be done using solenoids with parameters approximately like those given in the following table.

number	30
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	34
B_0 [T]	2

At this point the two lines end with additional bent solenoids to remove the dispersion in the beam that was introduced by the first bent solenoid. These bent solenoids would use a superimposed dipole field so the central momentum stays on-axis. The radius of the whole magnet can be ~30 cm.

3. First 201 MHz Guggenheim channel

We assume we can match into the Guggenheim using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	34
B_0 [T]	2

The properties of the magnets in the Guggenheim channel are given in the following table.

number	192
d [cm]	275
L [cm]	50
a [cm]	77
t [cm]	11
J_e [A/mm^2]	95
B_0 [T]	2.8

The number of magnets corresponds to 24 magnets/turn x 4 turns x 2 signs.

4. First 402 MHz Guggenheim channel

We assume we can match into the Guggenheim using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	68
B_0 [T]	4

The properties of the magnets in the Guggenheim channel are given in the following table.

number	672
d [cm]	137.5
L [cm]	25
a [cm]	38.5
t [cm]	5.5
J_e [A/mm^2]	385
B_0 [T]	5.5

The number of magnets corresponds to 24 magnets/turn x 14 turns x 2 signs. These magnets appear to have a serious problem with hoop stress that needs to be addressed.

5. Bunch merging

We assume we can match into the bunch merging section using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	51
B_0 [T]	3

The bunch merging section has a 180 m long drift followed by a 160 m long planar wiggler [6]. We assume the properties of the magnets in the drift channel are given in the following table.

number	360
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	17
B_0 [T]	1

The number of magnets includes both muon charges. The planar wiggler does not use solenoid focusing. The wiggler field is 0.78 T and the wiggler period is 2 m.

6. Second 201 MHz Guggenheim channel

We assume we can match into the Guggenheim using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	34
B_0 [T]	2

The properties of the magnets in the Guggenheim channel are given in the following table.

number	192
d [cm]	275
L [cm]	50
a [cm]	77
t [cm]	11
J_e [A/mm^2]	95
B_0 [T]	2.8

The number of magnets corresponds to 24 magnets/turn x 4 turns x 2 signs.

7. Second 402 MHz Guggenheim channel

We assume we can match into the Guggenheim using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	68
B_0 [T]	4

The properties of the magnets in the Guggenheim channel are given in the following table.

number	672
d [cm]	137.5
L [cm]	25
a [cm]	38.5
t [cm]	5.5
J_e [A/mm^2]	380
B_0 [T]	5.5

The number of magnets corresponds to 24 magnets/turn x 14 turns x 2 signs. These magnets appear to have a serious problem with hoop stress that needs to be addressed.

8. 805 MHz Guggenheim channel

We assume we can match into the Guggenheim using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	20
t [cm]	10
J_e [A/mm^2]	82
B_0 [T]	7

The properties of the magnets in the Guggenheim channel are given in the following table.

number	1152
d [cm]	90
L [cm]	15
a [cm]	6
t [cm]	10
J_e [A/mm^2]	170
B_0 [T]	11.4

The number of magnets corresponds to 24 magnets/turn x 24 turns x 2 signs.

9. Beam recombiner

We assume this section is similar to the beam separator, but arranged in the opposite order. The radii can be smaller because the emittance is smaller here. We assume we can match into the recombiner using solenoids with parameters approximately like those given in the following table.

number	12
d [cm]	100
L [cm]	50
a [cm]	20
t [cm]	10
J_e [A/mm^2]	59
B_0 [T]	5

Each of the two charge lines would go thru a bent solenoid with a superimposed dipole. This is followed by transport lines that take the beams from the parallel Guggenheim channels into the recombiner bent solenoid. We assume that ~30 m of transport would be sufficient using parameters approximately like those given in the following table.

number	30
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	51
B_0 [T]	3

We assume the recombiner bent solenoid has a 2 T field.

10. 50 T channel

The final transverse cooling is done with seven 50 T solenoids [7]. We assume we can match into the 50 T channel using solenoids with parameters approximately like those given in the following table.

number	6
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	85
B_0 [T]	5

The channel has seven 50 T magnets. These magnets have an inner layer of HTS, surrounded by layers of Nb_3Sn and NbTi. The detailed design of these magnets is a current R&D issue [7].

The amount of energy loss in the absorbers drops from ~100 MeV in the first cell to ~4 MeV in the last cell. At the same time the bunchlength increases from ~2 cm in the first cell to ~300 cm in the last cell. As a result the length of the seven reacceleration sections that replace the energy lost in the absorbers is ~5 m for each cell. We assume focusing in the RF sections then needs solenoids with parameters approximately like those given in the following table.

number	35
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	34
B_0 [T]	2

We assume that matching into and out of the RF accelerators uses solenoids with parameters approximately like those given in the following table.

number	84
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	85
B_0 [T]	5

11. Matching into preaccelerator

At the end of the 50 T channel the beam energy is ~10 MeV and the bunch length is ~300 cm. We need to use an induction linac to reaccelerate the beam to ~120 MeV. We assume that focusing in the induction linac is done using solenoids with parameters approximately like those given in the following table.

number	110
d [cm]	100
L [cm]	50
a [cm]	35
t [cm]	10
J_e [A/mm^2]	34
B_0 [T]	2

At this point we assume that the 200 MeV/c cooled beam can be matched into the first linac using a design similar to that used in Study 2 for a neutrino factory [8]. This used 33 solenoids whose properties are given in Table 5.9 in Study 2.

Summary

Based on the assumptions discussed in the previous sections the number of magnets required in the muon collider front end is 4093. Except for 3 normal-conducting solenoids at the target and 6 bent solenoids, the rest of these magnets are all straight superconducting solenoids. The breakdown of magnet count by subsystem is shown in the following table.

subsystem	**number**
precooler	422
beam separator	39
1st 201 MHz Guggenheim	204
1st 402 MHz Guggenheim	684
bunch merging	372
2nd 201 MHz Guggenheim	204
2nd 402 MHz Guggenheim	684
805 MHz Guggenheim	1164
beam recombiner	45
50 T channel	132
match to preaccelerator	143

Magnets in the 160 m long planar wiggler are not counted in this table.

References

[1] R. Palmer et al, A complete scheme for a muon collider, Proc. COOL 2007, Bad Kreuznach, Germany, p.77-81.

[2] R. Palmer et al, A complete scheme of ionization cooling for a muon collider, Proc. PAC07, Albequerque, New Mexico, p. 3193-3195.

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

[4] R. Fernow & J. Gallardo, Engineering parameter list for the Study 2a front end, NFMCC technical note 521, February 2008.

[5] R. Fernow & J. Gallardo, Front end design studies for a muon collider, Proc. PAC05, Knoxville, Tennessee, p. 2610-2612.

[6] J. Gallardo, Bunch merging, Talk at Muon Collider Design Workshop, BNL, December 2007.

[7] R. Palmer, Towards a conservative 50 T HTS magnet for final muon collider cooling, FNAL Beam Division technical note 2454, September 2006.

[8] Feasibility Study-II of a muon-based neutrino source, June 2001.