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TECHNICAL IMPLEMENTATION OF FEASIBILITY STUDY-II DESIGN

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Abstract

An updated Feasibility Study for a high-performance Neutrino Factory has been undertaken by Brookhaven National Laboratory (BNL) and the Neutrino Factory and Muon Collider Collaboration (MC). We describe the technical implementation of the facility. Details of the key components are shown, and R&D activities that need to be addressed to proceed toward a facility design are indicated.

1 OVERVIEW OF FACILITY

The Feasibility Study-II [1] configuration is based on the infrastructure available at BNL. Pions are produced by a 1-MW beam of 24-GeV protons from the AGS. The target is a mercury jet in a 20-T solenoidal field. The capture and decay section tapers the magnetic field smoothly down to 1.25 T. After the pions have decayed to muons, the resulting beam has a very large transverse emittance and a large energy spread. Phase rotation to reduce the energy spread utilizes three induction linacs having internal superconducting (SC) solenoidal focusing. To bunch the beam we use two RF systems, a primary system at 201.25 MHz and a second-harmonic system at 402.5 MHz. After bunching, the muons are cooled transversely in a 108-m cooling channel operating at a central momentum of 200 MeV/c. The cooling channel field is tapered in stages to give a lower beta function as the beam cools. The muons are subsequently accelerated rapidly, first to 2.5 GeV in a SC linac with solenoidal focusing and then to 20 GeV in a four-pass recirculating linear accelerator (RLA). The 20-GeV muon storage ring that serves as the source of decay neutrinos has a compact racetrack lattice with skew quadrupole focusing. For this Study, we assumed a detector located at the Waste Isolation Pilot Plant (WIPP) site in Carlsbad, NM. The experiment baseline is thus 2900 km. Though the Study includes the requisite upgrades to the AGS and considers possibilities for the detector, these will not be included in this paper. Here we restrict ourselves to describing the facility starting from the target and culminating in the storage ring.

2 TARGET

The Hg target material is introduced into the target solenoid via a nozzle; the jet velocity is 20–30 m/s. As shown in Fig. 1, the jet is at an angle of 100 mrad from the solenoid axis, and the proton beam is at an angle of 67 mrad, leading to a 33 mrad crossing angle between the beam and the jet. Beam pulses arrive in trains of six bunches spaced by 20 ms, with the trains coming at a 2.5-Hz rate. Thus, the instantaneous pulse rate is 50 Hz but the average rate is only 15 Hz.

The 20-T target solenoid comprises several nested coils. The inner three coils use normal conducting hollow-conductor technology. These are surrounded by a superconducting outer coil. There is also an iron plug, through which both the proton beam and the Hg-jet enter, that serves to make the field more uniform at the jet entry point. In view of the high-radiation in the target area, the complete facility (Fig. 2) is well shielded and designed to permit remote handling of components needing maintenance or replacement.

3 PHASE ROTATION

To improve the channel performance, we use three induction linacs with differing polarity and pulse length. IL-1 is 100 m long; IL-2 and IL-3 are each 80 m in length. The first two units operate at a gradient of 1.5 MV/m, the third operates at 1 MV/m. All three cores are
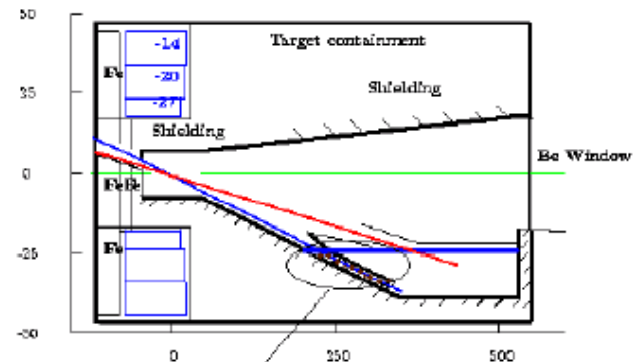

Figure 1: Schematic of target area showing target and beam orientation and beam dump.
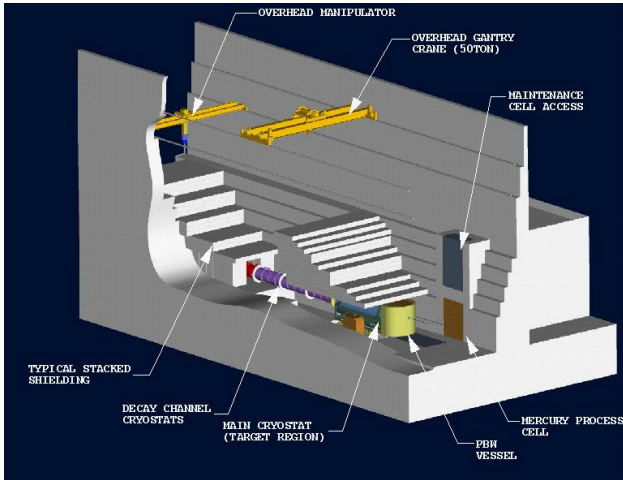
Figure 2: Illustration of target facility showing shielding and remote access capability.

Figure 4: Cross section of Lattice 2 cell.

mechanically identical, with an inner radius of 0.5 m and an outer radius of about 0.87 m. These parameters are similar to cores built for the DARHT accelerator [2]. The units will be driven by magnetic pulse compressors feeding suitable pulse forming networks. Superconducting solenoids are incorporated into the structure as indicated in Fig. 3.

4 BUNCHING AND COOLING

The cooling scheme is based on the SFOFO lattice type [1]. There are two different cell lengths, 2.75 m for the initial portion ("Lattice 1") and 1.65 m for the final portion ("Lattice 2"). Within each lattice, the magnetic field is increased in three stages. The last stage of Lattice 2 reaches a field of 5 T. A cross section of a Lattice 2 cell is shown in Fig. 4.
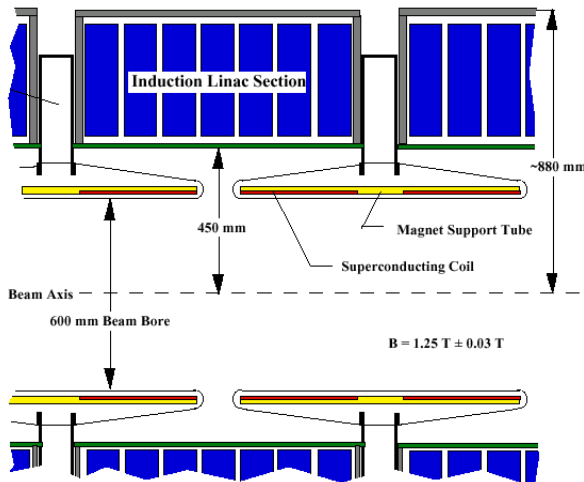

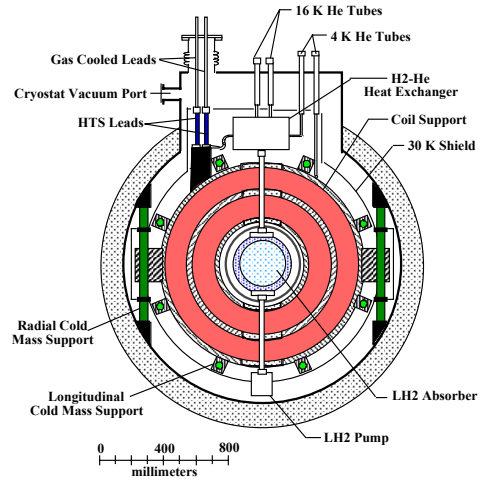Figure 3: Induction linac cells, showing internal SC solenoids.

The RF system uses 201.25 MHz normal conducting (NC) multicell RF cavities operating at gradients of 16–17 MV/m. Though the choice of frequency has not been truly optimized, it represents a sensible compromise between the conflicting needs for a large beam aperture and a high accelerating gradient. To increase the shunt impedance and on-axis accelerating field, the cavities are closed off with stepped Be windows [3]. Simulations have shown that this approach does not compromise the beam cooling effect of the channel.

The LH_2 absorbers are located between RF cavities. As indicated in Fig. 4, services are provided in the gap between solenoid coils. The absorbers require thin Al windows to contain the 1.2 atm liquid; suitable designs have been developed.

Solenoid magnets to provide the required field profile have been designed. The most challenging of these are the focusing coils surrounding the LH_2 absorbers in Lattice 2, where the forces are large. Designs that accommodate these forces have been developed.

5 ACCELERATION

The acceleration scheme, comprises a 433 m SC pre-accelerator linac followed by an RLA to reach 20 GeV. The SC linac has three different types of modules, short, intermediate, and long. Figure 5 shows the intermediate length module components. Each SCRF cavity is two cells, with a power coupler for each. The solenoids in this area are designed with an outer bucking coil and external shielding to reduce the fringe fields at the SCRF cavities to acceptable levels. Parameters for the SCRF system are summarized in Table 1.

In the RLA, quadrupole triplets are used for beam focusing. The overall system can accept the beam from the cooling channel and accelerate it to 20 GeV with only modest losses.
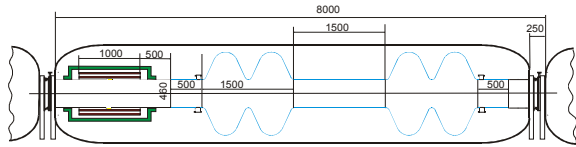
Figure 5: Intermediate length cell of SC linac.

Table 1: Main SCRF parameters.

No. of cryomodules	91
No. of 2-cell cavities	299
No. of input couplers	598
Overall length [m]	1015
Active length [m]	449
Filling factor	0.44
Total voltage [GV]	7.5
Average real-estate gradient [MV/m]	7.4
Total heat load [kW] at 2.5K/5–8K/40–80K	7.4/9.4/94
Cryogenic load[a] [kW] at 2.5K/5–8K/40–80K	11.1/14.1/141
AC power for refrigeration[b] [MW]	12.6 MW
Total peak RF power[c] [MW]	362 MW
Average RF power [MW]	16.3
AC Power for RF[d] [MW]	35.6
Total AC Power [MW]	48

[a]With 50% safety factor.

[b]Assuming efficiency multipliers of 600, 225 , 20 at 2.5K, 5–8K, and 40–80K, respectively.

[c]With 20% margin for control/losses.

[d]Efficiency multiplier = 2.

6 STORAGE RING

The 20-GeV storage ring layout and optics are shown in Fig. 6. As designed, about 40% of the muon decays will produce neutrinos for the detector; if decays produced in the matching portion of the straight section must be excluded, the percentage of usable decays will decrease somewhat. To aim at a detector 2900 km distant, the ring is tilted by 13º. To avoid penetration of the local water table at BNL, the ring will be partially above ground and shielded with a man-made hill.

The ring magnets are superconducting, with a field of about 7 T. Pancake coils above and below the median plane provide a dipole field while longitudinal staggering between upper and lower coils provides a strong skew quadrupole component. Attention is being paid to ensuring that field harmonics are acceptable for dynamic aperture, a nontrivial exercise for this design.

7 R&D ITEMS

The MC has a substantial R&D program now under way [4]. Here we list only topics directly related to Study-II:
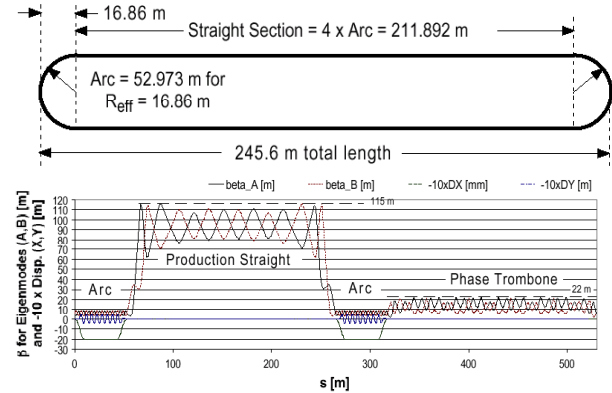

Figure 6: Layout (top) and optics (bottom) of 20 GeV muon storage ring.

- Verify Hg-jet performance and yield
- Test induction linac with internal SC solenoid and pulsed-power supply
- Verify gradient of NCRF cavities with solenoid
- Demonstrate means to counter multipactor
- Develop RF power source (multibeam klystron)
- Develop 201.25 MHz SCRF cavities
- Build shielded solenoids for preacceleration linac
- Verify harmonic content of storage ring magnets
- Define and test diagnostics

ACKNOWLEDGMENTS

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