BEAM-POWER DEPOSITION IN A 4-MW TARGET STATION FOR A MUON COLLIDER OR A NEUTRINO FACTORY

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Abstract

We present the results of power deposition in various components of the baseline target station of a Muon Collider or a Neutrino Factory driven by a 4-MW proton beam.

INTRODUCTION

The target station of a Muon Collider or a Neutrino Factory [1] requires a system of helium-cooled superconducting (SC) solenoid magnets and water-cooled resistive solenoids (RS) that will create a magnetic field of 20 T around the target area, which field will adiabatically decrease to 1.5 T over 15 m. The 20-T field around the free mercury jet target permits pions of $p_\perp < 200$ MeV/c to be captured in a 1.5-T solenoid channel of radius 30 cm, whereas use of only 1.5-T field at the target would require a radius of 80 cm.

The baseline target-station (see Fig. 1) includes 19 cable-in-conduit superconducting coils, and five copper, hollow-conductor resistive magnets. The peak value of the deposited power in the SC coils must be less than 0.1 mW/g to realize a 10-year operational lifetime against radiation damage [2]. To accomplish this, dense shielding, such as tungsten-carbide (WC) beads cooled by water flow, must be deployed inside the bore of the SC coils [3]. A 120-cm inner radius of the first 3 SC coils has been adopted [4] to accommodate the shielding, RS coils and services, and the pion-capture vessel, which leads to a stored magnetic energy over 3 GJ in the target-system magnets. The subsequent SC coil radii taper down to 45 cm, the inner radius of the 9th and higher coils.

We present simulation results for the deposited power in different parts of this baseline configuration, and discuss implications for modifications of the dimensions of the Hg-collection pool that serves the proton-beam dump.

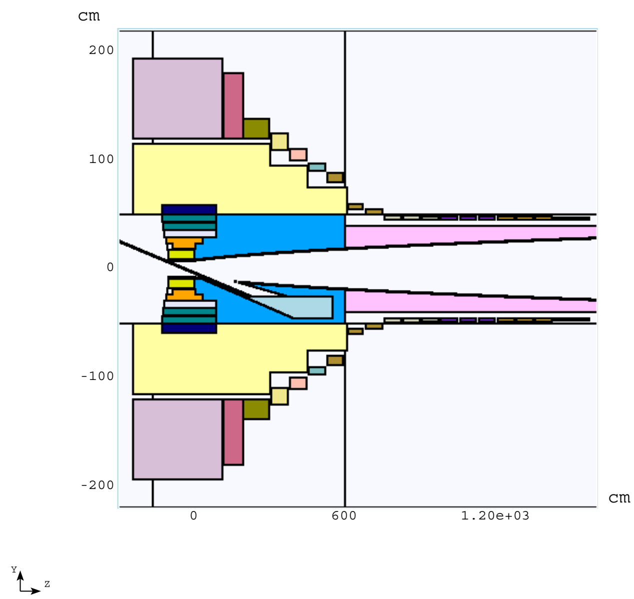

Figure 1: Vertical (y-z) section of the target system. Nineteen SC coils with fields from 20 down to 1.5 T surround the WC shielding, the 5 RS coils, the free mercury jet target, and the Hg collection pool inside the flared pion-capture vessel.

POWER DEPOSITION STUDIES.

The latest version of the MARS code (MARS1510) [5] with the MCNP cross-section libraries [6] for improved modeling of low-energy neutrons (less than 5 MeV) was used for the power-deposition simulations reported here. Studies [7] of the target station using the FLUKA code [8] are in good agreement with those based on the MARS code.

The studies assumed an 8-GeV proton beam with spot size at the target of $\sigma_x = \sigma_y = 0.12$ cm, which interacted with a 0.4-cm radius Hg jet with a speed of 20 m/s, subject to gravitational deflection.

A plot of simulated power deposition in a y-z (vertical) section of the target station is shown in Fig. 2, and some details of the deposited power in its various components are given in Table 1.

About 0.5 kW of power is deposited in the first superconducting coil, which is ~ 3.6-m long and 0.7-m thick. The total deposited power in all SC coils is about 0.9 kW, and the peak value is less than 0.045 mW/g, which is below the so-called ITER limit [2]. A little more than 200 kW will be deposited in the resistive magnets, and about 480 kW

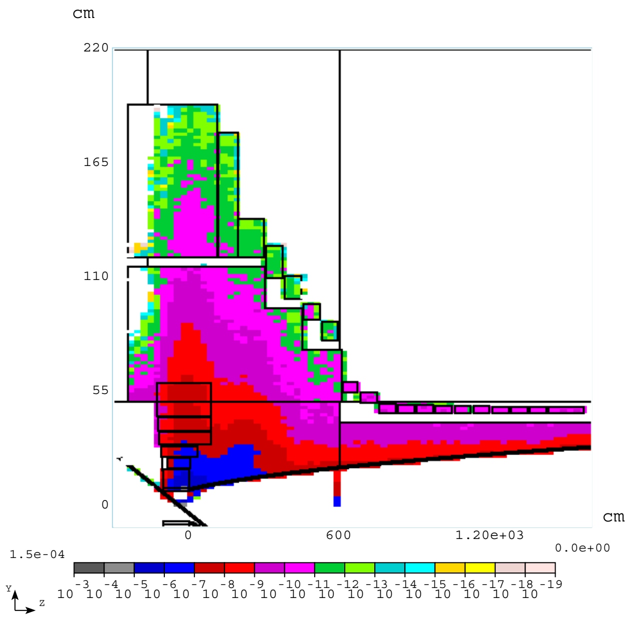

Figure 2: Vertical (y-z) projection of the density (in mW/g) of power deposited in the target region, according to a MARS15 simulation. The peak value in all SC coils is less than 0.045 mW/g.

Table 1: Power deposited (in kW) in 19 SC coils, 4 shielding areas (SH), 5 resistive magnets (RS), 3 beam pipes (BP), resistive-coil water cooling (RSC), Hg target, Hg pool, and downstream Be window.

Component	P (kW)
SC #1-19	0.86
SH #1-4	2228.6
RS #1-5	211.4
BP #1-3	481.9
RSC	7.1
Hg target	389.8
Hg pool	12.5
Be window	0.7
TOTAL	3332.8

in the beam pipe, mostly in the section immediately around the interaction volume. The Hg pool, as presently modeled, will receive only 12 kW, because it does not well contain the core of the shower of the beam protons that do not interact in the target. Some 666 kW of power is transported into the pion channel downstream of the target station, mostly carried by secondary protons.

Hg POOL AS PROTON BEAM DUMP

The low deposited power in the Hg pool, noted in Table 1, indicates that the pool is not sized properly to serve as the proton beam dump. The Hg pool was modeled with a width of only 12 cm, as in previous studies [9] with a 24-GeV beam energy. However, 8-GeV protons experience much larger deflections in the 20-T magnet, and the Hg pool must be enlarged accordingly. Furthermore, we are now considering proton beams that enter the magnet from the side, rather than from below the jet, which would increase the horizontal deflection of the beam.

The proton beam (and the Hg-jet target) make a vertical angle of 96 mrad to the solenoid axis [10], which maximizes collection of pions that emerge at large angles to the beam/jet. The upper surface of the Hg pool will be at $y = -25$ cm, so the proton beam would enter the pool about 240 cm downstream of the target (if undeflected by the 20-T solenoid) corresponding to $z = 205$ cm in our coordinate system (in which the center of the target is at $z = -37.5$ cm, and the downstream end of the interaction region is at $z = 0$).

We have considered 15 possible configurations of the

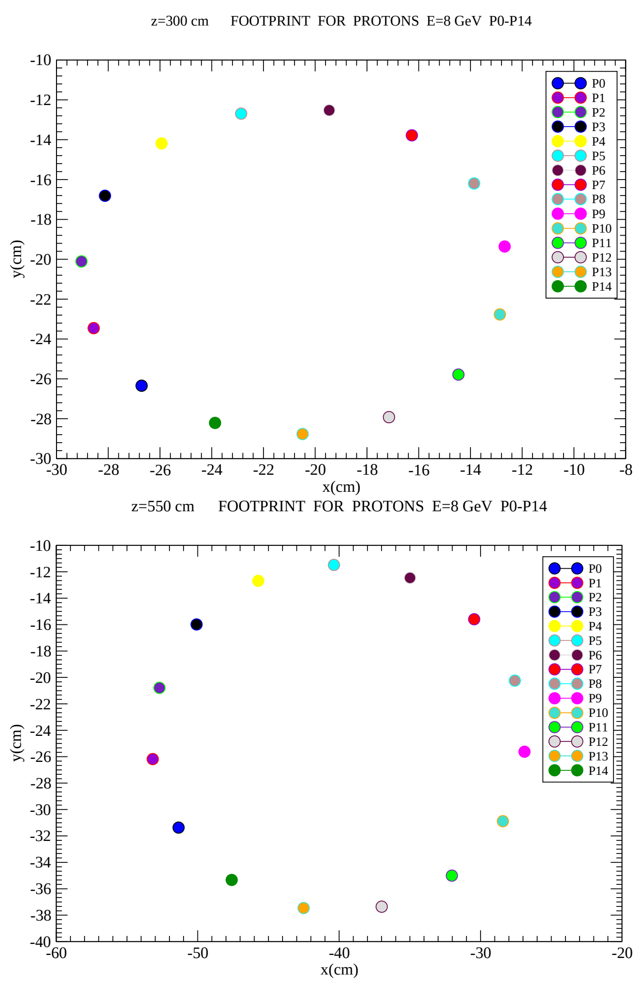

Figure 3: Proton-trajectory intercepts at $z = 300$ cm (top) and $z = 550$ cm (bottom) for 15 proton-beam configurations, each of which has the nominal beam/jet crossing angle at the center of the Hg target. The baseline configuration is that labeled P12.

proton-beam position and angle, such that at the center of the interaction region the proton beam has the nominal direction (96-mrad vertical angle to the solenoid axis), and overlaps well with the Hg-jet target. The x-y intercepts of these 15 proton-beam trajectories in the planes $z = 300$ and 550 cm are shown in Fig. 3.

Only the beam configurations labeled P0, and P11-14 will have entered the Hg pool by $z = 300$ cm, and only if the width of the pool is ± 27 cm at that distance. The configuration P12 is the baseline, and requires that the Hg pool have width ± 40 cm at $z = 550$ cm, if the beam is to remain inside the pool at that distance. For this width of the Hg pool, the power deposited there is about 230 kW (rather than only 12 kW for the pool of width ± 6 cm). Figure 4 sketches the proton-beam trajectory for the P12 configuration.

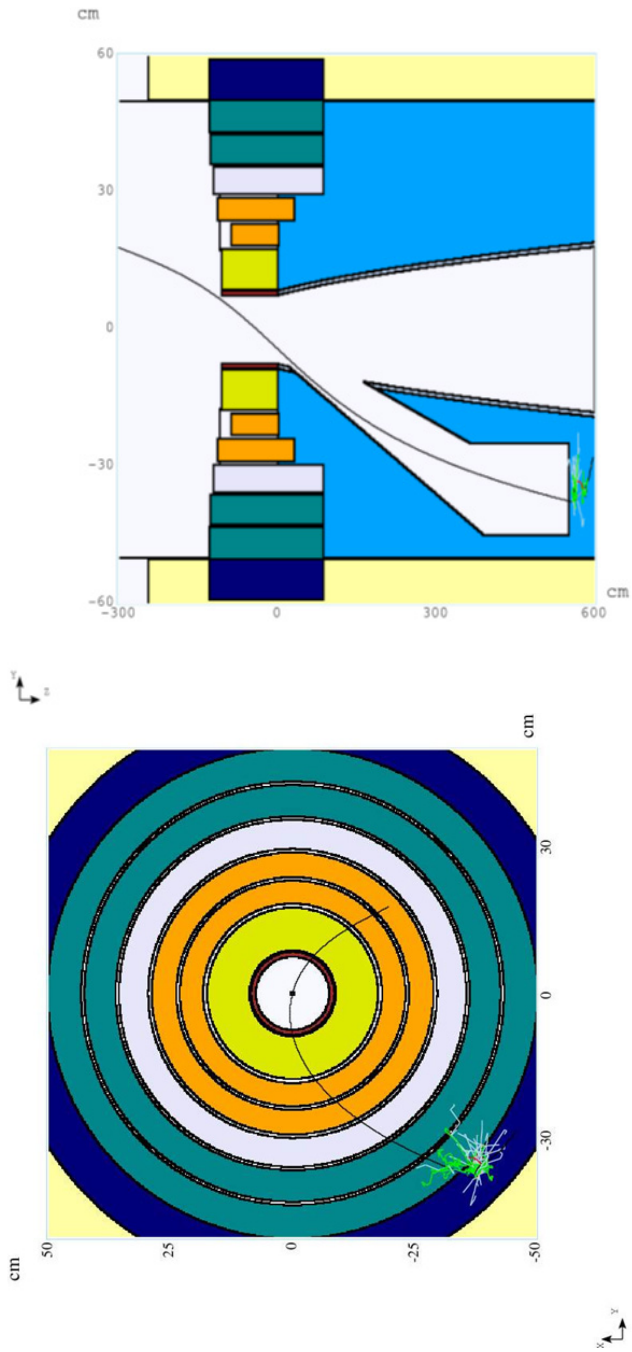

Figure 4: Top: Vertical (y-z, top) and transverse (x-y, bottom) projections of the (baseline) P12 proton-beam trajectory, neglecting interactions of the beam with the Hg target and pool.

CONCLUSIONS

The power deposition in different components of the baseline Muon Collider/Neutrino Factory target-station geometry was simulated using the MARS15 code with MCNP cross-section libraries. Massive shielding via tungsten-carbide beads out to a radius of 115 cm is sufficient to reduce the peak power deposition in the superconducting coils to below the so-called ITER limit of 0.1 mW/g, which should permit a 10-year lifetime of the coils. The initial configuration of the Hg pool, with width only ± 6 cm, was insufficient to serve as a proton beam dump. An increase of this width to ± 40 cm is needed according to the MARS simulations. A remaining issue is mitigation of the disruption of the Hg pool by the proton beam, and by the Hg jet itself.

ACKNOWLEDGMENTS

This work was supported in part by the US DOE Contract NO. DE-AC02-98CHI10886.

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