Muon Accelerator Program: Area System Concept Specification

Area System: Front End
MAP L2 Manager: D. Stratakis

Sub-System: Target
Revision Date: June 2, 2013

Introduction

The basic concept for the Target Subsystem as a solid or liquid-metal target that intercepts the proton beam inside a high-field solenoid magnet to capture both signs of secondary particles emerged already in 1995.[1] The present concept is for a graphite (or preferably carbon-carbon composite) target inside a 20-T solenoid field, which field "tapers" down to 2 T, used throughout the rest of the Front End, over 5 m. The yield of muons from the target is maximal at low kinetic energies, roughly 40 < KE < 180 MeV, which particles emerge at large angles to the proton beam, favoring a cylindrical target of small radius, and tilted slightly with respect to the magnetic axis to minimize reabsorption of particles if their helical trajectory passes through the target a second time.

The solenoid field is to be provided by superconducting coils, except for a 5-T resistive coil insert near the target. Radiation damage (particularly to organic insulators) limits the dose on these coils to about 10 MGray,[2] which translates to a peak power deposition of about 0.1 MW/g for a 10-year operations lifetime of 10^7 s/year. To achieve this performance, superconducting coils must have internal shields, here taken to be tungsten beads cooled by He gas flow. The required shielding is substantial, and leads to an inner radius of the superconducting coils of 1.2 m near the target; consequently the energy stored in the 20-T coils is about 3 GJ.

The target will also suffer radiation damage and must be replaced periodically. Operation at high temperature provides annealing of radiation damage and substantially longer target lifetime (as demonstrated at the CERN CNGS neutrino target[3]). The target will be radiation cooled, operating at about 1700° C for a carbon-based target at 1-MW beam power. It is encased in a double-walled stainless-steel vessel with intramural He-gas flow for cooling. This vessel will be replaced along with the target (and could be replaced with a different vessel for possible use of a liquid-metal-jet target at eventual higher beam powers).

---

[1] R.B. Palmer *et al.*, *Muon Colliders*, AIP Conf. Proc. *372*, 3 (1996).
[2] J.H. Schultz, *Radiation Resistance of Fusion Magnet Materials*, IEEE Fusion En. 423, (2003).
[3] E. Gschwendtner *et al.*, *CNGS, CERN Neutrinos to Gran Sasso, Five Years of Running a 500 Kilowatt Neutrino Beam Facility at CERN*, CERN-ACC-2013-0266.

The use of short proton pulses (3 ns rms) leads to severe stress ("thermal shock") on a solid target, which is mitigated by use of materials with high strength, high heat capacity and low thermal-expansion coefficient. A carbon-carbon composite can have thermal-expansion coefficient 1/5 that of graphite and is favored for operation at beam power higher than 1 MW or at repletion rates less than the nominal 60 Hz.

Design Requirements

Table 1: Preliminary design requirement for the Target Subsystem, as set by the Proton Driver upstream, and the remainder of the Front End downstream.

Parameter	Units	Value
Proton beam kinetic energy	GeV	6.75
Proton beam rep. rate	Hz	60
Proton pulse rms length	ns	3
Final solenoid field	T	2
Final radius of secondary beam	cm	23

Sub-System Parameters

Drawings of the Target System are available at
http://www.hep.princeton.edu/~mcdonald/mumu/target/graves/graves_140523b.ppt
A drawing with dimensions is at
http://www.hep.princeton.edu/~mcdonald/mumu/target/graves/20to2T5m120cm4pDL_dimensions.pdf

Table 2: Preliminary parameters for Target Subsystem of the Front End.

Parameter	Units	Value
Target (and proton dump) material		Graphite (or carbon-carbon composite)
Target density	g/cm^3	1.8
Target length	cm	80
Target radius	cm	0.8
Target (and beam) tilt angle	mrad	65
Dump length	cm	120
Dump radius	cm	2.4

A description of the optimization of the target parameters is given in
http://www.hep.princeton.edu/~mcdonald/mumu/target/Ding/ding_140529.pdf
Parameters of the magnet coils are given in the .xlsx file
http://www.hep.princeton.edu/~mcdonald/mumu/target/weggel/20to2T5m120cm4pDL.xlsx
A magnetic field map for -10 m < z < 10 m (where z = 0 at the center of the target) is at
http://www.hep.princeton.edu/~mcdonald/mumu/target/weggel/205to2T5m120cm4pDL.txt
Plots of the magnetic field are given at
http://www.hep.princeton.edu/~mcdonald/mumu/target/weggel/20to2T5m120cm4pDL.docx
The (unscattered) central proton ray for -10 m < z < 10 m is at
http://www.hep.princeton.edu/~mcdonald/mumu/target/Souchlas/20to2T5mDL_xyzr.xlsx

MAP: Area System Concept Specification

Technology Requirements

The technologies used in this Subsystem are categorized according the following rankings, which describe its feasibility:

1. Standard technology;
2. Technology which is a direct extrapolation from existing designs;
3. Technology which is sufficiently novel that a detailed engineering concept will be required and for which an engineering prototype demonstration may be necessary;
4. Technology which will require an R&D program to guide a successful design;
5. Technology which may require dedicated testing with beam in order to validate its design and operation.

Table 3: List of required sub-system technologies and their Feasibility Ranking

Technology	**Feasibility Rank**
Graphite target and dump	1 CNGS, J2K
Carbon-carbon composite (needs validation as to whether its good thermal-expansion coefficient remains at high radiation dose)	5
Stainless-steel walls for various vessels	1
Upstream proton beam window (Ti or Al)	1
Downstream beam windows (Be braised to SS)	1
Tungsten beads for shielding	1
He-gas-flow cooling of the W-bead shielding	3
Resistive coils with MgO or spinel insulation	2 (KEK)
Superconducting coils, cable-in conduit, for use in high radiation	2 (ITER)
Quench protection system for 3 GJ	2 (CERN CMS)
Remote handling systems for the above	1
The following technologies relate to possible use of liquid-metal jets	
The liquid-metal jet itself	2 (MERIT)
The nozzle for the liquid-metal jet	3
The liquid-metal collection pool, which is also the proton beam dump	3
The liquid-metal flow loop	2 (SNS)