Costing Methodology and Status of the Neutrino Factory.

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Abstract

The International Design Study for the Neutrino Factory will produce a reference design report in 2013 that will contain a detailed performance analysis of the Neutrino Factory and a cost estimate. In order to determine the cost a number of engineering features need to be included in the accelerator physics design, which can require the physics design to be re-optimised. The cost estimate is determined in such a way as to make efficient use of the engineering resources available and to simplify the process of modifying the physics design to include engineering features.

This paper presents details of the methodology used to determine the cost estimate and the current status of each subsystem.

INTRODUCTION

The International Design Study for the Neutrino Factory (IDS-NF) [1] aims to deliver a reference design report of the whole facility by the end of 2013. This report will contain a detailed cost breakdown to inform a decision to build the facility. The effort to cost the Neutrino Factory (NF) is also part of the EUROnu [2] project which will compare a next-generation superbeam, the NF and a β-beam based on physics reach, accelerator and detector performance and cost.

The NF is divided into the following systems: the proton driver; the target, capture and decay section; the muon front-end, muon acceleration; and the muon decay ring. Due to the limited engineering resources available it is not possible to produce a detailed bottom-up cost estimate and so a different approach needs to be taken relying on extrapolation from known costs. The general methodology follows the steps outlined in Figure 1. Starting with the physics design, engineering features are added to produce schematic drawings and CAD layouts. This may have an impact on the physics design, which may require re-optimisation. Following this, a cost model is constructed allowing cost performance analyses to be performed, which may in turn affect the physics design. Since the NF utilises a variety of technologies, the cost model has to be tailored for each of the systems as detailed in the following sections.

PROTON DRIVER

There are currently three options for the proton driver: a Project-X based option at Fermilab; an SPL based option at CERN; and an ISIS upgrade option at RAL. These projects are independent of the IDS-NF and so the costing will be done separately though each proton driver option will have parts that are specific to the NF and these will be costed for the IDS-NF. Figure 2 shows the high level breakdown structure for each of the three options.

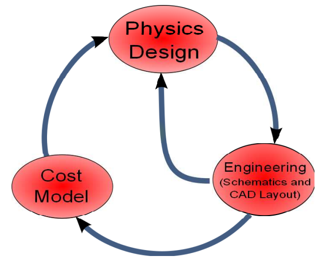

Figure 1: Diagram showing the general methodology used to cost the Neutrino Factory.

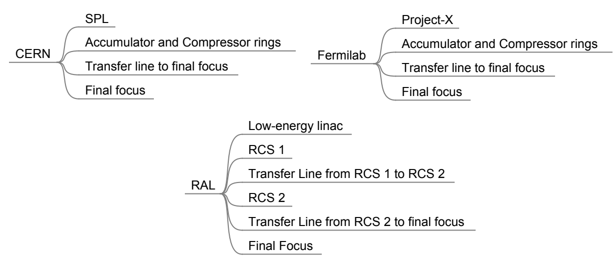

Figure 2: High-level breakdown of the three proton driver options for the IDS-NF.

For the Project-X and SPL based options, additional accumulator and compressor rings, a transfer line to the target hall and the final focus need to be costed. For the purposes of estimating the cost of the magnet and RF system for the rings, the design will be taken from [3]. The design of the transfer line and final focus is currently being worked on. For the RAL based option, the low-energy linac and the RCS 1 will be costed as part of the ISIS upgrade plan. The design of RCS 2 is being developed and will be costed based on the cost estimate of RCS 1.

TARGET, CAPTURE AND DECAY

The focus of the costing effort so far has been on the baseline option of the liquid mercury jet. The main items to be costed are: the target module; magnets; magnet shielding; cryogenics; remote handling and hot cells; and civil engineering.

The target module includes the mercury flow loop and the utilities needed for it. The volume of mercury for the IDS-NF target is similar to that of SNS and so the cost estimate of the target module is based on the as-built cost of the SNS target module. The current design of the pion capture system utilises a series of large aperture solenoids to taper the field from 20 T down to 1.5 T over a distance of 15m. The cost of the superconducting magnets is the sum of two components: a normal conducting equivalent cost per kg; and the cost attributed to the volume of superconductor required. This cost model was applied to all the magnets in the capture and decay section. These magnets will require shielding and the cost of this is estimated based on an average cost per kg for tungsten. An estimate of the cryogenic load is required in order to determine the cost of the cryogenic system.

The civil engineering of the target hall (which goes from the beginning of the final focus to the beginning of the muon front-end) and remote handling requirements are based upon recent design studies for future multi-megawatt proton target stations, e.g. LBNE, and the cost has been estimated by scaling by length.

MUON FRONT-END

The muon front-end consists of a buncher, phase-rotator and a cooling section. All three sections utilise densely packed superconducting solenoids and normal conducting cavities. This technology is similar to that used for the MICE experiment and so the cost estimate of the modules for the buncher, phase-rotator and cooling sections have been based on the cost of the MICE modules. Figure 3 shows a schematic drawing of one module of the buncher, which is based on the MICE module. The spacing between the coils has been modified from the original physics design to allow space for the RF power input coupler. Similar drawings have been done for the phase rotator and the cooling section. The frequency of the cavities in the buncher through to the cooling section vary from 320 MHz to 201 MHz whereas the cavities in MICE are all 201 MHz. For the purposes of costing it is assumed that this variation in frequency will not significantly affect the cost. Other costs such as cryogenics and diagnostics have been scaled from the FFAG cost model. In order to obtain a better estimate of the cost of the cryogenic system for the muon front-end a study of the cryogenic load will need to be done.

MUON ACCELERATION

The muon acceleration section starts with a 244 MeV to 900 MeV linac followed by two recirculating linacs (0.9 GeV to 3.6 GeV and 3.6 GeV to 12.6 GeV) and a 25 GeV non-scaling FFAG.

For the muon acceleration system, much of the engineering effort has focussed on the details of the FFAG. The FFAG is broken down into: magnet modules and power

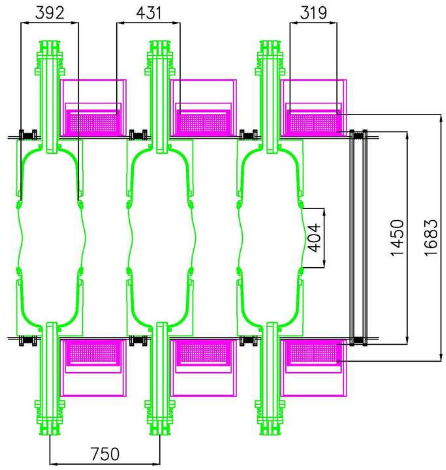

Figure 3: Schematic drawing of the buncher module showing the arrangement of the coils, cavities and RF power input couplers.

supplies; SC cavity modules; RF power; kickers and septa; cryogenics; diagnostics; vacuum; controls; mechanical, survey and alignment; and buildings, infrastructure and services. Figure 4 shows a schematic drawing of the FFAG cell.

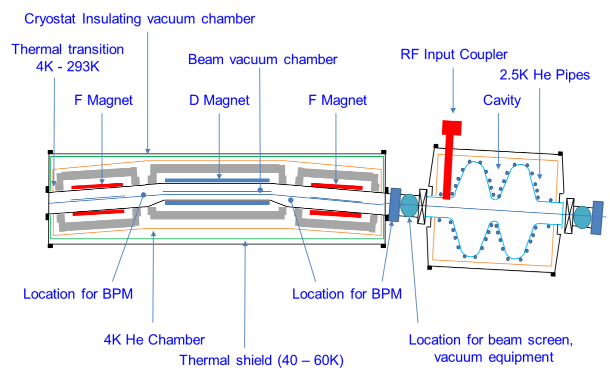

Figure 4: Schematic drawing of the FFAG cell.

There are a number of technology choices for the FFAG magnets but for the purposes of costing, the same technology as the J-PARC neutrino beam combined function superconducting magnets was chosen. This allows estimating the cost based on as-built costs. The technology for producing the high-gradient superconducting 201 MHz cavities is less well understood. In the past niobium sputtered onto copper cavities have been used but these have not been able to deliver the gradients required at 201 MHz[4]. In the absence of a technological solution, a cost model was developed based upon engineered solutions for next-generation light sources. It is obvious that the technology is different between the cavities for next-generation light sources and those required for the FFAG. However, an accurate cost model cannot be developed until the technology for the FFAG cavities has been proven. Details of the civil engineering were estimated based upon detailed engineering studies for a next-generation light source. The cost of cut-and-cover tunnels, ancillary buildings and services were estimated by scaling with length. Other major cost drivers for the FFAG are: the cryogenics plant; RF power supply and distribution; and the kicker power supplies.

The linac is composed of a series of superconducting solenoids and 201 MHz cavities, arranged in two types of cryomodules. The first type of cryomodule contains one solenoid and a single cell 201 MHz superconducting cavity. The other contains one solenoid and a double cell 201 MHz superconducting cavity. Costing of the cavities has been based on the cost model for the FFAG and costing of the solenoids has been based on the same cost model used for the capture solenoids. The cost model for the RLAs is based upon the cost model for the FFAG with the exception of the magnets. The cost estimate of the quadrupole magnets in the linac and arcs was based upon the cost estimate for the quadrupole magnets in the muon decay ring. The cost estimate of the dipole magnets is currently being worked on. All other costs such as cryogenics and diagnostics have been scaled by length from the FFAG cost model. In order to obtain a better estimate of the cost of the cyrogenic system for the linac and RLAs a study of the cryogenic load will need to be done. The linac and RLAs were originally vertically stacked but this would be more expensive from the perspective of distribution of RF and cryogenics. The layout is now horizontal, which requires a small modification to the injection chicanes of the RLAs.

MUON DECAY RING

The design presented in the Interim Design Report [5] required two racetrack decay rings (each approximately 760m long and 85m wide), one tilted at $36°$ and the other tilted at $18°$. Having the beamline inclined at such an angle will provide challenges for the installation and maintenance of components and so the design of the tunnel and crane will require careful consideration. Some effort has gone into investigating solutions for this and Figure 5 shows a conceptual drawing of what the tunnel cross-section may look like. The floor has been stepped to allow installation to be easier and space has been included for personnel enclosures, which may be required to comply with health and safety legislation (e.g. if cryogens are vented into the tunnel where personnel are working). The crane system is likely to be ratcheted and can be mounted off the tunnel's ceiling.

The cost of the magnet system and civil engineering was estimated based upon experience of costing the ILC. There are a couple of superconducting dipole magnets that cannot be scaled from ILC magnets and work is progressing on estimating the cost of these. Other costs such as cryogenics and diagnostics have been scaled from the FFAG cost model. There is some room for cost optimisation of the croygenic system based upon where the plant is located. In the current design, only the arcs require superconducting magnets. This means the cryogenic plant for the arc located deep underground could either be placed on the surface, requiring transport of cryogens over several hundred meters; or the cryogenic plant could be located close to the arc, requiring additional tunnelling.

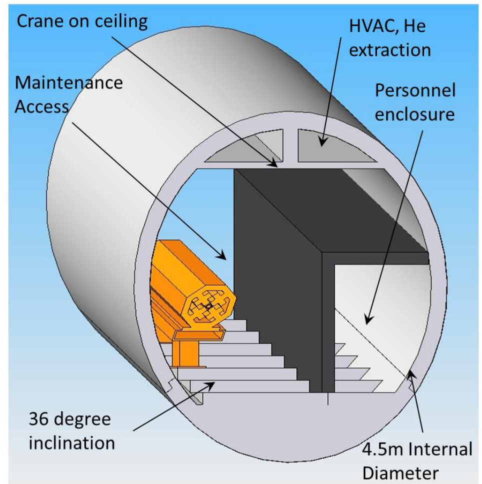

Figure 5: Cross-section of the decay ring tunnel showing the stepped floor and personnel enclosure.

SUMMARY

Much progress has been made towards including engineering features in the physics design of the NF and developing cost models. In light of recent measurements of the neutrino oscillation parameter θ_{13}, the baseline physics design of the IDS-NF has changed. This has simplified the design, requiring a lower muon beam energy and only one decay ring. This change means the decay ring and final muon acceleration section has to be re-optimised. However, this will not affect the methodology used to cost the NF. Work is on-going to complete the cost estimate for the current baseline of the IDS-NF and this will be published in the EUROnu final report.

REFERENCES

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