High priority will be placed on this work and the intention is to engage a broad cross section of the collaboration in this process. The task force will be charged to deliver a report by July 2016. Based on the report of this task force and input from the DUNE Technical Board, the DUNE Executive Board will refine the DUNE strategy for the near detector.

5.5 A Strategy for Implementing the LBNF Beamline

The neutrino beamline described in this CDR is a direct outgrowth of the design [1] developed for the CD 1 in 2012. That design was driven by the need to minimize cost, while delivering the performance required to meet the scientific objectives of the long-baseline neutrino program. It includes many features that followed directly from the successful NuMI beamline design as updated for the NOvA experiment. It utilizes a target and horn system based on NuMI designs, with the spacing of the target and two horns set to maximize flux at the first, and to the extent possible, second oscillation maxima, subject to the limitations of the NuMI designs for these systems. The target chase volume — length and width — are set to the minimum necessary to accommodate this focusing system, and the temporary morgue space to store used targets and horns is sized based on the size of the NuMI components. Following the NuMI design, the decay pipe is helium-filled, while the target chase is air-filled and air-cooled.

The LBNF beamline is designed to utilize the Main Injector proton beam with energy between 60 and 120 GeV and beam power from 1.0 to 1.2 MW respectively, as will be delivered after the PIP-II upgrades [2]. The ability to vary the proton beam energy is important for optimizing the flux spectrum and to understand systematic effects in the beam production, and to provide flexibility to allow the facility to address future questions in neutrino physics which may require a different flux spectrum. To allow for higher beam power that may be enabled by future upgrades to the Fermilab accelerator complex beyond PIP-II, those elements of the beamline and supporting conventional facilities that cannot be changed once the facility is built and has been irradiated are designed to accommodate beam power in the range of 2.0 to 2.4 MW for proton beam energy of 60 to 120 GeV. These elements include the primary beam, target hall, decay pipe and absorber, as well as all of the shielding for them. Components that can be replaced, such as targets and horns, are designed for the 1.2-MW initial operation. In general, additional R&D, which is not part of the LBNF Project, is required to develop those components to be able to operate at the higher beam power.

Since the 2012 CD-1 review, the beamline design has evolved in a number of areas, as better understanding of the design requirements and constraints has been developed. Some of these design changes have come to full maturity and are described in this CDR. Others require further development and evaluation to determine if and how they might be incorporated into the LBNF neutrino beamline design. They offer the possibility of higher performance, flexibility in implementation of future ideas, or greater reliability. The beamline facility is designed to have an operational lifetime of 20 years, and it is important that it be designed to allow future upgrades and modifications in order to exploit new technologies and/or adapt the neutrino spectrum to address new questions in neutrino physics over this long period. The key alternatives and options under consideration and the strategy for evaluating and potentially implementing them are summarized here. They are described in more detail elsewhere in this CDR or its Annexes.

Further optimization of the target-horn system has the potential to substantially increase the neutrino flux at the first and especially second oscillation maxima and to reduce wrong-sign neutrino background, thereby increasing the sensitivity to CP violation and mass hierarchy determination, as discussed in Volume 2: The Physics Program for DUNE at LBNF. The optimization work there is ongoing and may yield further improvements beyond those currently achieved. Engineering studies of the proposed horn designs and methods of integrating the target into the first horn must be performed to turn these concepts into real buildable structures that satisfy other requirements such as reliability and longevity. These studies will be carried out between CD-1 and CD-2 to determine the baseline design for the LBNF target-horn system. Since targets and horns must be replaceable, it is also possible to continue development of the target-horn system in the future and replace the initial system with a more advanced one or one optimized for different physics. Such future development, beyond that necessary to establish the baseline design at CD-2, would be done outside of the LBNF Project.

The more advanced focusing systems

called 'optimized beam configuration' in vol 2 sec 3.7.2; let's use that terminology here to distinguish from 'enhanced' which is about the target, also in 3.7.2

described in Volume 2: The Physics Program for DUNE at LBNF utilize horns that are longer and larger in diameter and that are spaced farther apart than the reference design, which would require a target chase approximately 9 m longer and 0.6 m wider than the reference design. It cannot be ruled out that further optimization, or new designs called for in the future to explore new questions, may require additional space beyond this. Also, the larger horns will require larger space for temporary storage of used, irradiated components, requiring, in turn, an increase in the size of the morgue or a revision of the remote handling approach. Between CD-1 and CD-2, studies will be done to determine not only the geometric requirements from the final baseline target-horn system, but also to estimate the dimensions needed to accommodate potential future designs.

The material, geometry and the structure of the target assembly itself can have significant impact both on the effective pion production and the energy spectrum of pions, which in turn affect the neutrino spectrum, and on the reliability and longevity of the target, which affects the integrated beam exposure. Potential design developments range from incremental (e.g., changing from the reference design rectangular cross section, water-cooled graphite target to a cylindrical helium-cooled target), to more substantial (e.g., changing target material from graphite to beryllium), to radical (e.g., implementing a hybrid target with lighter material upstream and heavier material downstream and perhaps constructed of a set of spheres captured in a cylindrical skin). New designs beyond the current reference design are also needed in order to accommodate the higher beam power (up to 2.4 MW) that will be provided by the PIP-II upgrade. Target development will largely be carried out in the context of worldwide collaborations on high-power targetry such as the Radiation Damage In Accelerator Target Environments (RaDIATE) collaboration, and not within the LBNF Project. The LBNF design must be such that it can fully exploit future developments in target design.

The length and diameter of the decay pipe also affect the neutrino flux spectrum. A longer decay pipe increases the total neutrino flux with a larger increase at higher energies; a larger diameter allows the capture and decay of lower-energy pions, increasing the neutrino flux at lower energy as described in Volume 2: The Physics Program for DUNE at LBNF. The dimensions also affect the electron-neutrino and wrong-sign backgrounds. Unlike targets and horns, the decay pipe cannot be modified after the facility is built, making the choice of geometry particularly important. The reference design values of 204 m length and 4 m diameter appear well matched to the physics of LBNF,

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but studies to determine the optimal dimensions continue. The cost of increasing the decay pipe length or diameter is relatively large, as is the impact on the absorber of increasing the diameter. Therefore, studies of the decay pipe must include comparisons of the tradeoffs between investment in the decay pipe versus investment in other systems, e.g., a larger target hall complex, more advance target-horn systems, or more far detector mass. Ongoing studies will continue to be carried out jointly by LBNF and DUNE between CD-1 and CD-2 to determine the baseline decay pipe geometry.