Addendum to the Proposal: Enhancing the LBNF/DUNE Physics Program

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I. PREPARATION ACTIVITIES

No major R&D is required for the proposed STT. The core technology to build the STT is well established, as various straw detectors have been built and operated for decades. The conceptual design considered for our proposal is similar to the ATLAS TRT [6–8] and COMPASS [9, 10] straw trackers. Many modern detectors designed for precision physics and the search for rare processes are based upon straw trackers minimizing the overall mass. Recent examples include NA62 [11], COMET [12], SHiP [13], and Mu2e [14]. The STT design represents an innovative application to neutrino physics of the straw technology used by such modern experiments.

The main activities required before entering the detector construction phase are the ones related to the engineering and optimization of the STT design. They include (a) the construction of detector prototypes and (b) the prototype testing with test-beam exposures. The time allocated to this preliminary phase is about two years from the start of the project.

A. Prototyping and R&D

The following R&D and prototyping activities have been identified:

- Development of the nuclear targets. The main targets to consider are the CH_2 polypropylene radiators, the graphite (C) and Ca targets. Small target prototypes will be built to optimize the design, size, protection against external agents, mechanical support and integration with the frames of the STT modules.

- Development of the readout electronics. The default front-end electronics (VMM3) will be tested together with possible alternatives using STT prototypes, to optimize the functionality, the design of the FE boards, and the integration with the STT modules.

- STT prototypes. A small initial prototype $1.8m \times 0.6m$ of a XXYY STT module will be built and tested to validate the construction tolerances, acceptance criteria and the requirements for the FE electronic readout. The initial prototype will be followed by three half-scale $1.8m \times 1.8m$ prototypes of the STT modules to test the mechanical construction and the integration with the nuclear targets and readout. These STT prototypes will undergo extensive testing to validate the production design both in the laboratory and with test-beam exposures.

B. Test-beam exposures

We plan to irradiate the STT prototypes including different nuclear targets and readout electronics to various particles using the CERN test-beam facilities:

- Low energy $E \leq 5$ GeV μ, π, e, p to test the detector response to different particles, particle identification, track reconstruction and interactions in the nuclear targets.

- Neutron irradiation to calibrate the absolute neutron detection efficiency of STT including the various nuclear targets. This measurement is important to achieve an accurate measurement of the absolute antineutrino flux using $\bar{\nu}p \to \mu^+ n$ at low Q^2.

II. COST AND SCHEDULE

Item	Cost (USD)
Procure straws (Lamina Tubular Technology, UK)	1,429,120
Procure end plugs	437,891
Procure wire spacers	403,647
Procure crimping pins	386,941
Procure anode wire (Luma metall AB, Sweden)	456,288
Procure other miscellaneous components	123,925
Procure radiator foils (Bloomer Plastics Inc., USA)	112,000
Procure mechanics & C-fiber frames	3,821,194
Procure STT tools	569,000
Procure safety equipment & consumables	100,838
Procure gas system	1,590,000
Procure cooling system	1,060,000
Procure target parts	122,112
Procure front-end electronics (VMM3 & boards)	1,250,000
Procure back-end electronics	1,144,236
Procure HV components	291,654
Procure LV components	302,378
Procure cables & connectors	455,000
Procure DAQ system	82,055
Total	14,138,279

TABLE I. Estimated core costs for the construction of the proposed STT.

The default configuration for the proposed STT is based upon 80 modules with transverse dimensions $3.5m \times 3.5m$, each composed of four straw layers XXYY. Assuming a single readout at one end of the straws, the total number of electronic channels is 224,000. We estimated the core costs for the construction of the complete STT using a mixture of updated quotes from vendors, costs of similar detector components used in different experiments, as well as the cost estimate of the larger STT from the DUNE CDR [1]. Table I summarizes the corresponding costs for the various items. The costs of the engineering, module assembly and test are not included as they depend upon the project sharing among the interested institutions.

We will decide upon a primary production center for the STT modules. To this end, we can benefit from the activities planned for the DUNE CDR [1] and from the technical collaboration with institutions involved in the construction of other straw detectors. It would be useful to use 2-3 different production sites for the STT modules in order to reduce the time required for the construction of the STT. Furthermore, specific items like the readout electronics, the gas and cooling systems, the nuclear targets, etc. can be allocated to different institutions. With conservative assumptions on the number of assembly lines and manpower at a single production center, we expect to complete the STT construction, testing and installation in a period of less than 4 years. This estimate is consistent with the main schedule of the DUNE experiment and would make the proposed STT ready for the first neutrino beam available in LBNF.

The risk associated to the project is relatively small. As discussed in Sec. I, the conceptual design is based upon well established technology and is similar to the ATLAS TRT [6–8] and COMPASS [9, 10] straw trackers. Low mass straws have been successfully developed for various modern projects including NA62 [11], COMET [12], SHiP [13], and Mu2e [14]. All the components required to build the STT can be manufactured industrially by vendors to be assembled into the final STT modules at the project production centers. Furthermore, the proposed STT is an evolution of the tracker from the reference ND design in the DUNE CDR [1]. As such, its design, cost and schedule successfully passed the technical and DOE CD1 reviews [3–5].

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