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Prof. Ing. Igor Jex, DrSc., Dean
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Dear Prof. Ing. Jex,

I am writing in response to a request to serve as a referee in evaluating and providing a report on the thesis **Searching for Lightweight Dark Matter in the NOvA Near Detector**, authored by Ing. Filip Jediný. Please find below my referee's report on the thesis manuscript.

The submitted thesis describes a novel search for low-mass dark matter, often referred to as Light Dark Matter (LDM), in the NOvA Near Detector (ND). The LDM would be hypothetically produced during the collision of protons with the fixed target of the Neutrinos at the Main Injector (NuMI) beam, as a byproduct of the production of the neutrino beam measured by the NOvA detectors. These LDM searches are accessible at the Near Detectors of running and future accelerator experiments, like NOvA, T2K, DUNE, SBND, and LDMX, or at dedicated beam dump experiments, like MiniBooNE, SHiP, and BDX. The parameter space covered by LDM searches is very complementary with searches conducted at colliders, and allows probes of vector and baryonic portals, so the topic and goals of this thesis are very timely and relevant. Further, the analysis procedures developed within the thesis data analysis work provide a template for LDM searches at future accelerator neutrino facilities, in particular for DUNE ND searches that will probe a similar slice of parameter space.

A very rich LDM phenomenology has developed over the last decades, rendering it unwieldy to test the various scenarios and types of DM mediators in a single analysis, and many of them are not experimentally accessible by the NOvA ND. Therefore, the thesis research focused on testing the specific Neutral Vector Portal model, with a vector field mediator V kinetically mixed with Standard Model mediators. In this scenario, the mediator V produced at the NuMI target can decay into DM particles $\chi\chi^{\dagger}$, which in turn may scatter elastically with an electron in the detector. The model specifically probes the parameter space where $m_V = 3m_{\chi}$, with kinetic mixing strength $\varepsilon = 2\times10^{-5}$. The signal for this search is an isolated forward-boosted electromagnetic shower reconstructed within the NOvA ND, with dominant backgrounds arising from neutral current neutrino on electron scattering, charged-current electron neutrino interactions, and neutral-current interactions with π^0 production, with subsequent decay of the π^0 into two photons.

Establishing the sensitivity reach for this LDM probe required the author to develop a new PYTHIA-based simulation of dark matter production in the NuMI target, and of the 4-vectors of electrons scattering off the χ particles traveling within the NOvA ND volume. Those 4-

vectors are then fed into the regular GEANT4-based detector simulation, while the neutrino backgrounds are simulated using the already existing FLUGG, GENIE, and GEANT4-based NOvA ND simulation. The LDM signal is reconstructed using pre-existing NOvA algorithms, and the signal/background separation employed in the thesis was adapted from machine-learning visual algorithms trained in identifying electron and pion-induced showers in particle interactions represented by pixel map images. The systematic uncertainties considered were adopted from those assessed in previous NOvA neutrino analyses and were evaluated in the same fashion. Finally, the NOvA ND data sample analyzed was divided into a signal region and a sideband region, according to the kinetic energy and angular distribution of signal and backgrounds. The analysis was optimized using only data from the sideband region, while the signal region was kept blinded until all selection criteria were frozen. In conclusion, the methodology described is sound and follows the standards expected for analyses of experimental data within a collaboration like NOvA's.

The data analysis carried out finds no evidence for the existence of LDM consistent with the scenario and parameter space explored, with the final result expressed as an upper limit on the cosmologically-relevant DM self-annihilation parameter Y. Therefore, the primary goal of the thesis of probing the existence of LDM in the NOvA ND for certain phenomenological scenarios has been achieved. Insofar as the scientific value of the results is concerned, the limit obtained compares very favorably to existing null results probing the same LDM scenario, and appears to be world-leading in some regions of parameter space. These results also establish both the feasibility of these searches within the near detectors of long-baseline accelerator neutrino experiments, and provide a template for such searches in future experiments.

In my estimation, the thesis results exposition would benefit from the presentation of a direct comparison of the limit obtained with existing limits in the literature, as well as with projected sensitivities for the same parameter space to be probed at future facilities. Given the large neutrino interaction statistics collected at the NOvA ND, the assessment and understanding of systematic uncertainties impacting the result are paramount. To qualify the robustness of the results obtained, it would be very beneficial to include a brief study in the thesis showing how the NOvA ND LDM sensitivity is affected by varying the dominant uncertainties affecting the measurement, such us flux and cross section systematics.

With that being said, I believe the thesis as it stands meets all the requirements for attribution of a Ph.D. degree following a successful defense, and thus recommend it for presentation and defense.

Sincerely,

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