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AI-driven neutrino diagnostics and radiation-hard beam instrumentation for next-generation neutrino experiments

Thursday 14 August 2025 09:30 (20 minutes)

The Long Baseline Neutrino Facility (LBNF) at Fermilab will deliver a high-intensity, multi-megawatt neutrino beam to the Deep Underground Neutrino Experiment (DUNE), enabling precision tests of the three-neutrino paradigm, CP violation searches, neutrino mass ordering determination, and supernova neutrino studies. To accelerate DUNE's physics reach and ensure robust beam operations, we propose an integrated AI-driven framework with real-time diagnostics and radiation-hardened instrumentation. At its core is a Real-Time Beam Integrity Monitor using a physics-informed Digital Twin. By reconstructing pion phase space from muon profiles and exploiting magnetic horn optic linearity, it enables spill-by-spill beam correction and flux stabilization. By using this approach, flux-related systematics could be reduced from 5% to 1%, potentially accelerating the discovery of CP violations by four to six years. Complementing this, a US–Japan R&D effort will deploy a LAPPD-based muon monitor in the NuMI beamline. ToF measurements can be acquired with picosecond precision using this radiation-hard system, enhancing sensitivity to horn chromatic effects. Simulations confirm strong response to these effects. ML models predict beam quality and horn current to sub-percent accuracy from muon data, enhancing anomaly detection and stability. This scalable, AI-enabled strategy improves beam fidelity, reduces systematics, and sets a new standard for high-power accelerator operations.

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Yes

Would you like to submit this poster in student poster session on Sunday (August 10th)

No

Footnotes

Funding Agency

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Yes

Author: GANGULY, Sudeshna (Fermi National Accelerator Laboratory)

Presenter: GANGULY, Sudeshna (Fermi National Accelerator Laboratory)

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