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A Narrow-Band Neutrino Beam from HIAF for Precision Neutrino-Nucleus Cross-Section Measurements

As next-generation long-baseline experiments DUNE and Hyper-Kamiokande enter a systematics-dominated era, neutrino-nucleus cross-section uncertainties—particularly for antineutrinos in the 0.3–2.5 GeV range—have become the leading limitation on δ_{CP} extraction. We present a novel narrow-band neutrino beam produced by instrumenting the High Energy Fragment Separator (HFRS) at China’s HIAF as a momentum-selecting pion decay channel. The HFRS first dipole selects pions with $\Delta p/p \approx \pm 2\%$, yielding a neutrino energy spread of 4–5% FWHM—one order of magnitude narrower than conventional horn-focused beams—with wrong-sign and intrinsic ν_e contamination below 1%. A distinctive feature is the use of $^{16}\text{O}^{8+}$ primary ions, which produce nearly symmetric π^+ and π^- yields, enabling ν_μ and $\bar{\nu}_\mu$ beams of comparable purity and statistics—a capability absent at existing facilities. G4Beamline simulations show a flux-shape uncertainty of 1% and a path to flux normalisation below 2% via in situ calibration. A 500-ton tracking calorimeter at 50 m would collect more than 10^4 CC events with a 3-year run, enabling differential cross-section measurements with sub-percent statistical precision.

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