Contribution ID: **51** Type: **Talk**

Optimizing the directional detection of low-energy electron recoils

Friday 14 June 2024 15:30 (15 minutes)

Modern high-definition gaseous time projection chambers (TPCs) enable us to not only measure the energy but also the direction of low-energy nuclear and electron recoils. This capability is highly sought after for a range of applications, including directional coherent elastic neutrino-nucleus scattering (CEvNS) measurements, dark matter searches within the neutrino fog, and studying solar neutrinos. Historically, the emphasis within the directional recoil detection community has been on nuclear recoils for dark matter detection. Recently, the directional detection of electron recoils has re-emerged as a potential avenue for probing solar neutrinos. We introduce a methodology for predicting the angular resolution of electrons in gas, which can be used to optimize the parameters of directional detectors for electron scattering. Furthermore, we discuss a novel deep learning model capable of analyzing 3D data to probabilistically predict direction. Tested on simulated electron recoil data, this model significantly surpasses conventional approaches in performance and offers accurate estimates of directional uncertainty. Although our primary focus is on directional electron scattering, the methodologies discussed are widely applicable to directional detection experiments.

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Session Classification: Talks