Sub GeV Proton-Pion Identification in the Recoil Tracker and Calorimeter of the LDMX

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Introduction

There are many models for dark matter currently being tested- one of the simplest posits that dark matter arose as a thermal relic from the early universe. Experiments testing this hypothesis have thus far remained in the GeV-TeV range, leaving MeV-GeV “Light Dark Matter” unexplored. LDMX aims to probe this lower mass range with new sensitivity using electron beam fixed target collisions and missing energy/momentum searches to identify and explore several dark matter interactions.

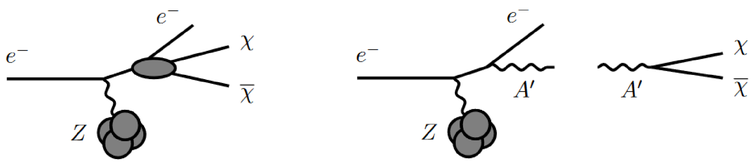

Figure 1: Feynman diagram for direct and mediated production of dark matter. These reactions are of main importance to LDMX.

Proton-Pion Production

Bremsstrahlung photons and electrons may interact with the target nuclei to produce protons and pions that deposit low energy in the calorimeter. In the interest of eliminating this background, the shower characteristics of the respective products in the recoil tracker and electromagnetic calorimeter (Ecal) were analyzed for differences to use in creation of a Boosted Decision Tree (BDT)

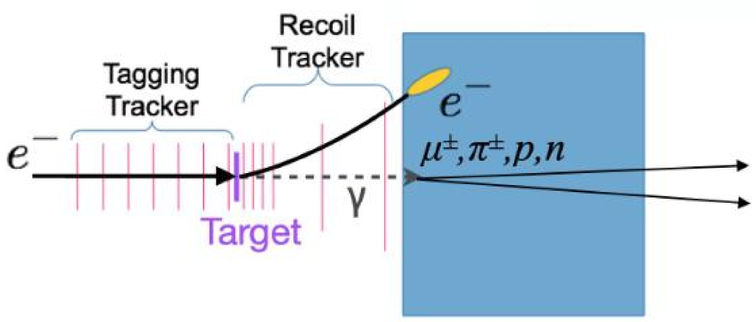

Figure 2: Detector layout. Illustrated in the recoil tracker and Ecal is an example photon reaction producing protons or pions.

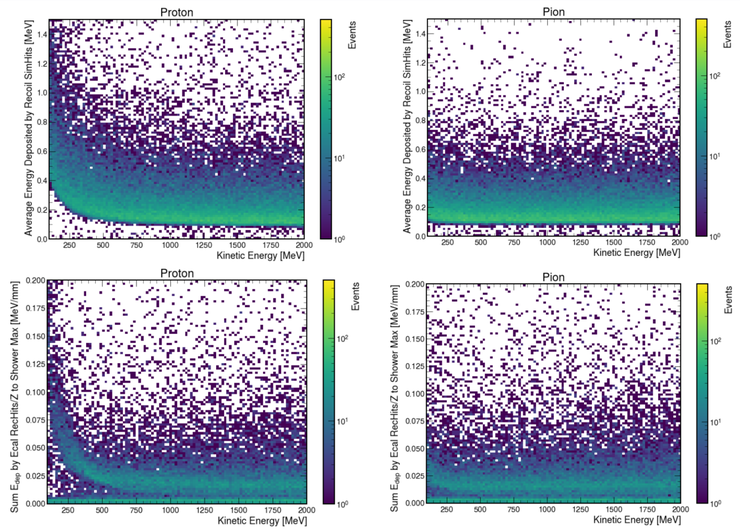

Figure 3: Top: 2D histogram of Average energy deposited in recoil tracker vs. kinetic energy of particle for proton and pion. Bottom: 2D histogram of sum of energy deposited in Ecal divided by the distance to the shower max vs. kinetic energy of particle for proton and pion. These two features, along with the most probable energy deposited and shower width (for Ecal only) were used to train the BDT.

Methods

The LDMX simulation framework was used to simulate a proton and pion gun placed in front of a tungsten target sheet, with the kinetic energy of the particles flatly distributed from 100-2000GeV. A SciKit-Learn Histogram Gradient Boosted Tree (BDT) was trained on a dataset consisting of 150,000 events (samples) with 7 features (3 for a simulated recoil tracker and 4 for a reconstructed Ecal). ROC curves were generated for analysis of the classification power of the BDT.

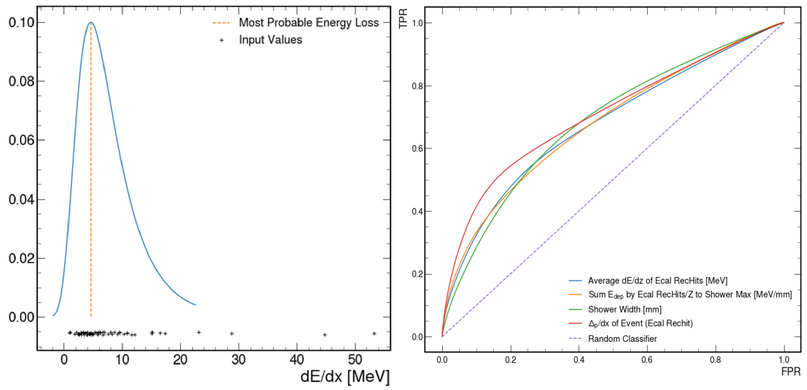

Figure 4: Left: Sample fitting of one event to a moyal distribution. The fitted moyal distribution is plotted above the 1D dataset (“Input Values”) of hit dE/dxs. Right: ROC curve of the 4 features of the Ecal, for events with particle kinetic energies between 100-417 MeV. The True Positive Rate (TPR) is for the classifying of protons.

Results & Conclusions

The final BDT is a good beginning for a classification ensemble but leaves much to be improved. For one, the $\langle dE/dx \rangle$ and most probable energy loss may be improved/coalesced by truncating the upper and lower energy hits. This would produce a more representative average in events with singular high energy depositions. The methodology around dE/dx for the reconstructed Ecal also may be improved- particles that stopped earlier had their dEs divided by smaller dzs, due to an absorber width two-three times smaller for the early layers (1-6) than the Final layers (26-34). A potential fix may be to weigh each hit according to a ratio using the previous deposition. Future quantities of interest for particle ID include the furthest layer hit in the Ecal, and the standard deviation of energy weighted layer numbers hit.

BDT Results- Left: ROC curve for classification of protons (TP) against pions with all events considered. Right: ROC curve when only events with hits registered in the recoil tracker and Ecal are considered.

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