PROCEEDINGS OF SCIENCE

Muon-electron elastic scattering events in INO-ICAL prototype

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The INO-ICAL prototype stacks have been extensively used to establish performance benchmarks of Resistive Plate Chambers for the final ICAL detector. Various studies have been undertaken using the data recorded by these prototype detectors. However, the studies primarily focused on single muon events. The existing traditional algorithms used for event analysis discard any events that exhibit a different topology from a straight line, assuming such events to be noise. While this approach leads to the loss of many interesting events in the data, it can also reduce the physics potential of the detector. In this context, we have developed a ML model to identify the new event topologies, specifically those identical to muon electron elastic scattering events. We present the overview of the algorithm and the potential outcomes from this study.

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1. Introduction

The objective of the India-based Neutrino Observatory (INO) is to study neutrinos by employing an Iron Calorimeter (ICAL). The detector stack at Tata Institute of Fundamental Research (TIFR), Mumbai was one of the first prototypes built to study the detector performance for the INO, and has been collecting data collecting data since prior to 2012 [1]. It consists of 12 Resistive Plate Chambers (RPC) of dimension 1 m × 1 m, each separated by an air gap of 16.8 cm [2]. As cosmic muons pass through the stack, the Data acquisition (DAQ) system stores the hits corresponding to the layers in the stack and timing information. Studies predominantly focus on single-muon events and therefore train algorithms to discard events with topologies distinct from a straight line considering them to be noise. This limits the physics scope of the detector and disregards diverse events occurring within the detector.

2. $\mu - e$ Elastic Scattering

A preliminary investigation unearthed some interesting event topologies, of which were those suggestive of muon-electron elastic scattering events. Such events indicative of $\mu - e$ elastic scattering had a simple topology characterised by three coplanar tracks, one of the incoming muon and the other two corresponding to the outgoing muon and outgoing electron respectively, with a common vertex identified by the intersection of the tracks. Subsequently, such events indeed corresponding to $\mu - e$ scattering were identified in Geant4 simulations and a Machine Learning (ML) model was developed to identify and perform a dedicated analysis on $\mu - e$ elastic scattering events in the INO-ICAL prototype data.

3. ML Scheme to Identify $\mu - e$ Elastic Scattering Events

A Python algorithm was developed for generating events for training, having topology consisting of a single particle entering the detector volume and two outgoing particle tracks, all three having a common vertex lying within the detector volume. For this purpose, XGBoost, a high-performance implementation of gradient-boosted decision trees was used [3]. Some of the predicted events are illustrated in figure 1. The strip hits were considered as features and the events were labelled as 1 for $\mu - e$ elastic scattering events and 0 for other events.

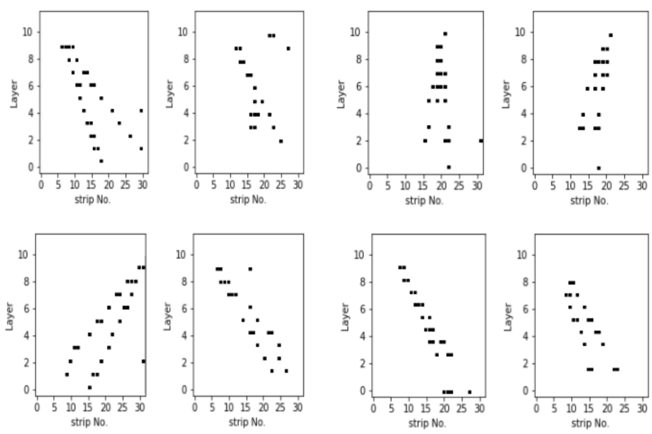

Figure 1: $\mu - e$ Elastic Scattering events predicted by the XGBoost model in the real cosmic muon data.

4. Physics Potential

For a muon with mass m_μ and energy E_μ elastically scattered by an electron with mass m_e at rest, the scattering angles, with respect to the initial muon momentum, θ_μ and θ_e, of the final state particles in the laboratory frame are given by [4]

$$\tan\theta_\mu = \frac{2\tan\theta_e}{\left(1+\gamma^2\tan^2\theta_e\right)\left(1+g_\mu^*\right)-2} \tag{1}$$

where, γ is the Lorentz factor and

$$g_\mu^* = \frac{E_\mu m_e + m_\mu^2}{E_\mu m_e + m_e^2}. \tag{2}$$

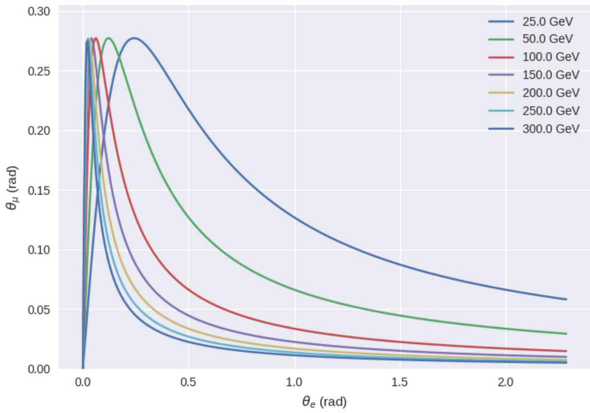

Figure 2: Correlation between θ_e & θ_μ for various initial muon energies, obtained theoretically. The μ & e tracks can therefore be differentiated by the larger scattering angles of electrons.

Equations 1 & 2 indicate that the initial muon energy can be theoretically estimated from the θ_e and θ_μ values measured experimentally. The maximum scattering angle of the muon, however, is constrained by the relation [4]:

$$\theta_\mu^{max} = \sin^{-1}\left(\frac{m_e}{m_\mu}\right) = 4.8 \text{ mrad}. \tag{3}$$

This may lead to implications in the energy estimation due to:

- The ambiguity in distinguishing tracks of the μ and the e when the scattering angles of both are <4.8 mrad, in detectors where particle discrimination is not possible
- The effect on the angular resolution attributed to detector spatial resolutions and uncertainties associated in vertex finding.

On the contrary, the electron scattering angle has a much wider range, as seen in figure 2. Meanwhile, the energy of the scattered electron is related to θ_e as [4],

$$\frac{E_e}{m_e} = \frac{1+\beta^2\cos\theta_e}{1-\beta^2\cos\theta_e} \tag{4}$$

with β given by

$$\beta = \frac{\sqrt{E_\mu^2 + m_\mu^2}}{E_\mu + m_e}. \quad (5)$$

Assuming β to be unity, if the electron energy is available, limits on muon energy can be obtained using these equations. Also, the electron energy can be partially retrieved by the number of layers it crosses, as shown from the simulation results presented in figure 3.

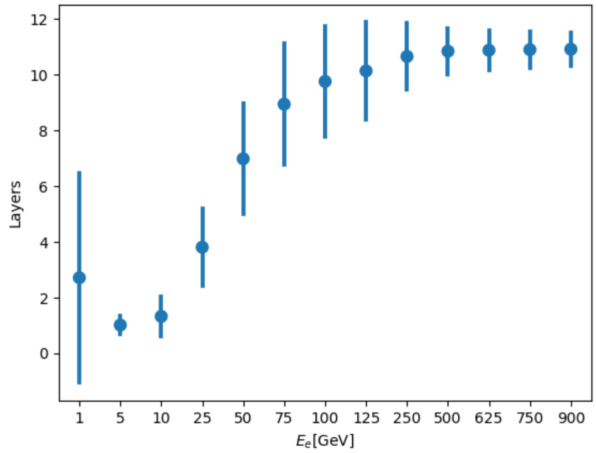

Figure 3: Distribution of maximum RPC layers crossed by electrons with energies in range 1 MeV - 900 MeV.

5. Summary

Preliminary studies have been done on classifying plausible $\mu - e$ Elastic Scattering Events uncovered in the real data using ML. The ongoing work is to analyse the uncertainties in the muon energies using simulations and to study other physics possibilities.

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