Classification Algorithm for Dark Matter Search using Skipper-CCD

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Introduction

Skipper-CCDs:

- Electron-counting silicon sensors,
- Many application fields.

Dark Matter (DM) Direct Research:

- Search for sub-GeV DM-electron interactions,
- **SENSEI@MINOS** (2018):~100m overburden with 2g active mass
- **SENSEI@SNOLAB** (2021):~ 2km overburden with 100g active mass,
- **OSCURA** (2028) : ~2km overburden with 10kg active mass.

New analysis tool needed: machine learning (ML).

This work: tagged dataset for ML training

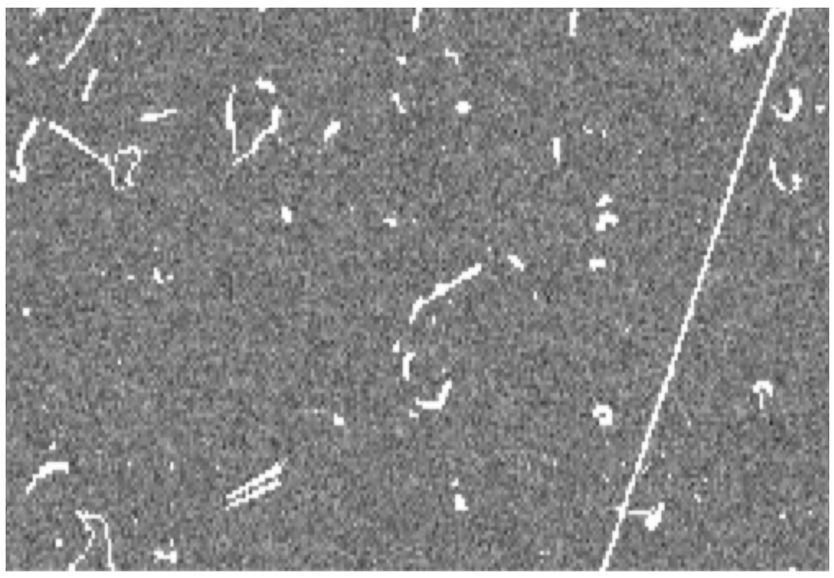

Fig. 1 Skipper-CCD Readout at MINOS

Can you count how many electrons are there?

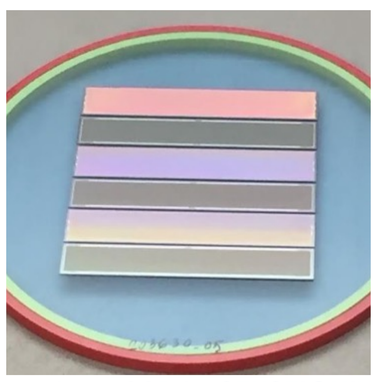

Fig. 2 skipper-CCD for SENSEI@MINOS.

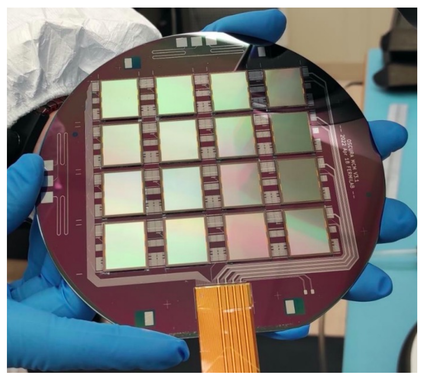

Fig. 3 OSCURA multi-chip module setup.

Geant4 Simulation and Classification Algorithm

Geant4 Simulation:

- Create a pure sample of electron, muon or photon events on a CCD,
- Study different parameters of particle tracks for classification

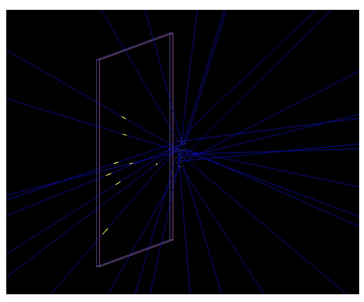

Fig. 4 Geant4 Simulation Setup with 30 500 MeV muons, 1cm away from CCD.

Fig. 5 Geant4 simulation: photons in CCD.

Classification Algorithm:

- 14 different parameters,
- Two main categories:
  - Deposited charge distribution,
  - Shape of particle tracks.
- Output same-size plain text files into folders,
- SENSEI@SNOLAB data to optimize the algorithm for experiment result,
- SENSEI@MINOS data to generate the tagged dataset.

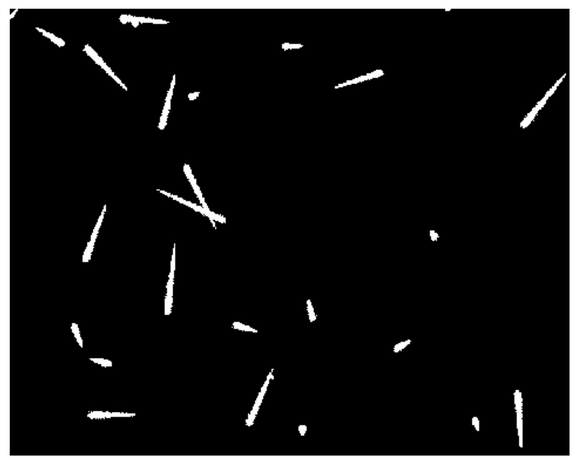

Fig. 6 Geant4 simulation: muons in CCD

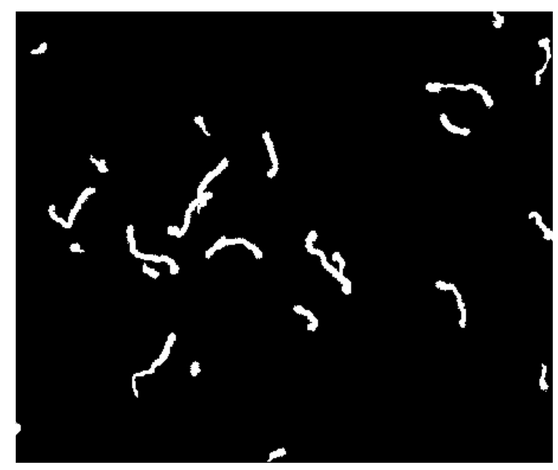

Fig. 7 Geant4 simulation: electrons in CCDs

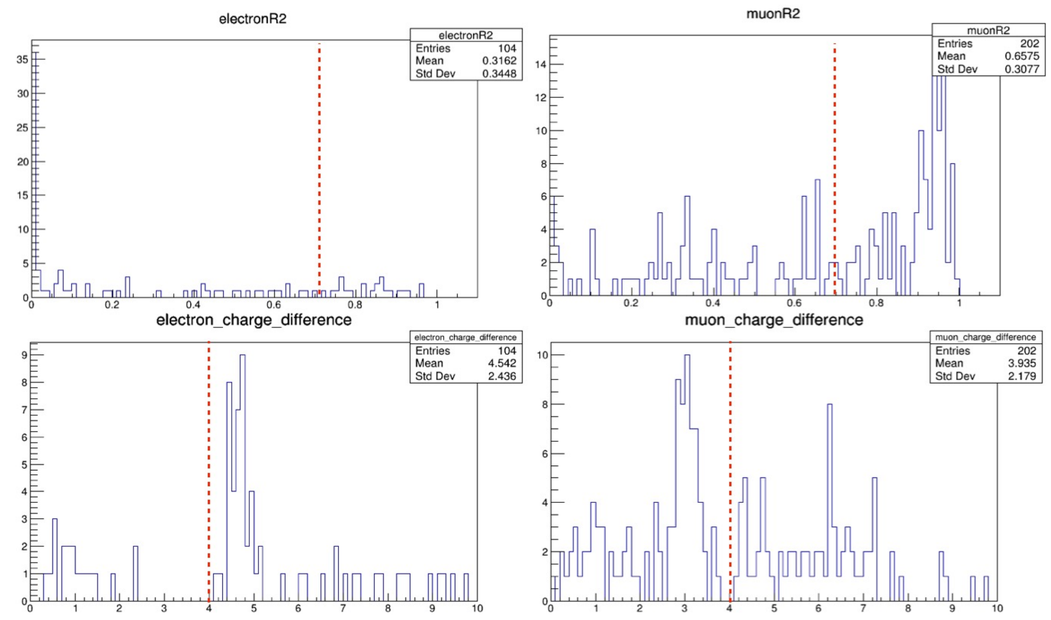

Fig. 8 Histograms of properties of electrons and muons with cutoff values in classification algorithm. (Top) R-squared value of each track. (Bottom) maximum difference of charges deposited in each pixels of each particle track.

Conclusion

In this project, I used ROOT framework with C++ for data analysis and Geant4 for simulating different particles' interaction with the detector to study the characteristic of their tracks. I prepare the tagged dataset for machine learning training both the real experiment data taken in MINOS and simulation data from Geant4.

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