Particle trajectory visualization and identification with Timepix detectors

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MoEDAL experiment

- Monopole and other exotics detector at the LHC
- Designed to search for manifestations of new physics signified by highly ionizing particles (HIPs)
- Seeks to answer fundamental questions surrounding the existence of monopoles, dark matter and extra dimensions
- Key player in the search for new fundamental symmetries of nature, alternative mechanisms of mass generation, etc.
- In essence, this experiment aims to trap these long-lived HIPs and take photographic evidence of these particles [1].

[1] James L Pinfold, *The MoEDAL Experiment at the LHC*, Physics Department, University of Alberta, EDP Sciences, DOI: 10.1051 20147100111
Timepix detector

- Measures the radiation deposited by passing particles
- 3 modes on readout electronics [1] : Medipix (photon counting), TimePix (time of arrival of photons in detector medium), and time-over-threshold (ToT) (radiation visualization)
- Relies on silicon based semiconductor detector chips to track particle events -> array of semiconductor chips can be represented in an image form

Timepix detector

- Activated chips return count values. A group of activated sensor chips adjacent to each other are known as clusters, and there is a systematic approach to classifying the clusters to identify which particle caused those clusters.
- Each type of particle will leave a distinct pattern of deposited radiation as it passes through (depends on its mass, charge and unique interactions with external EM fields).
Previous Works

● have sought to classify the particles and interactions that appear in the Timepix detector using the shapes of clusters of activated semiconductor chips.

● classification of such clusters was performed by researchers in the Langton Star Centre as part of CERN@school, in an activity similar to the Juggernaut project of the LHCb collaboration, which uses the Zooniverse’s Galaxy Zoo technology.

● With the first algorithm from Report 1 (J. Flores & A. Shaa June 2016) for cluster classification, there were difficulties in differentiating between SW, brancher and crossover clusters (more on cluster types later).
Project goals

- We offer insight into a computerized method of cluster classification, developed for fast identification and processing of large data sets into six main cluster categories.
- This process is intended to precede the distribution of clusters to participants in a Zooniverse type project for meticulous identification for the sake of the MoEDAL experiments research, and improved student learning within the CERN@school framework.
Cluster classification: Clusters and Pixels

- Clusters define distributions of deposited energy in the TimePix detector and can be treated as an array of pixels.
- These arrays or images can be represented by matrices $A_{ik}$ in which the indices represent spatial coordinates $(i,k)$ each associated with a count $C$ or pixel value.
Cluster variables

- To differentiate between clusters, some topological cluster variables were extracted from existing CERN@School cluster analysis code [1].
- Topological cluster variables [2] included size, counts, number of inner/edge pixels, aspect ratios, center of cluster, radius, density, linearity, horizontal/vertical neighboring pixel distance, and chi-squared value (for evaluation of the goodness of fit).

[1] CERN@School GitHub, Queen Mary University, London
Cluster Types

BOXY

BRANCHER

LOOPER

CURVED

SLUG

SW

STRAIGHT

CROSSOVER
Cluster Sorting Algorithm
Results

• Efficiency from Report 1 (Jessica Flores & Ameir Shaa June 2016)
  \[ E_{\text{eff}} = 0.35 \]

• Using new and improved algorithm,

  \[ E_{\text{eff}} = 0.85 \]

This must be tested against a larger data sample and for sample bias in selection cuts!
Summary

• The algorithm implemented within Python sorts clusters into 6 categories.
• Categories were inherited from the work of the CERN@School project [1]
• The presented cluster sample was initially sorted manually into a category
• The algorithm was written to reflect this manual selection using topological properties of clusters

Summary and Moving Forward

- The efficiency of the algorithm: $E_{\text{eff}} = 0.85$

- Algorithm must be tested against larger data samples to ensure it is not biased by characteristics of small data sample

- More data has been provided and will be analyzed with this algorithm.
Moving Forward

• Will continue to improve algorithm to classify clusters with more efficiency.
  – Biggest challenges: differentiating crossovers from branchers -> will look into junction detection algorithms (have already been implemented in ImageJ but need to be implemented in OpenCV for us to be able to use this method).

• Have worked on MoEDAL simulations for the past month
  – Looking at phase space and spatial distributions of monopoles generated in simulations and spatial distribution of monopole hits in MMT detector (10,000 event simulations with 4000 GeV beam energy)
    • Have varied monopole mass (200-500 GeV), charge (1-6 gD) and spin (0 and \( \frac{1}{2} \))
    • Still in the process of understanding the results of correlation analyses of simulation output
    • Involves becoming more familiar with Gauss simulations, MoEDAL software packages, Geant4, MadGraph and ROOT (special thanks to Matti Kalliokoski and Daniel Felea for helping with this)
Cultural Experiences

THANK YOU!

… Questions?