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

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[1] T. Whyntie, H. Bithray, J. Cook, A. Coupe, D. Eddy, R.L. Fickling, J. McKenna, B. Parker, A. Paul & N. Shearer *(2015) CERNschool: demonstrating physics with the Timepix detector*. Contemporary Physics, 56:4, 451-467, DOI: 10.1080/00107514.2015.1045193

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).

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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 differentating 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.

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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.

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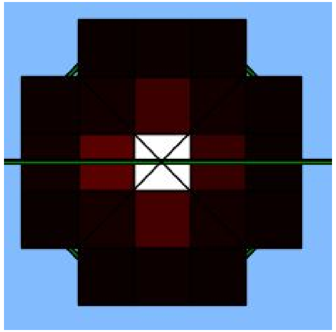
Cluster variables

- 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).

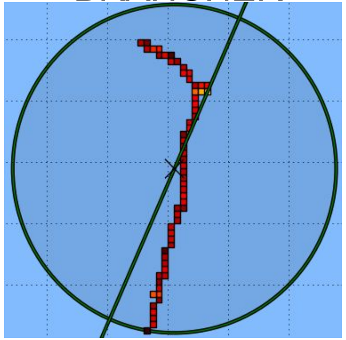
[1] CERN@School GitHub, Queen Mary University, London
[2] T. Whyntie, H. Bithray, J. Cook, A. Coupe, D. Eddy, R.L. Fickling, J. McKenna, B. Parker, A. Paul & N. Shearer *(2015) CERNschool: demonstrating physics with the Timepix detector*. Contemporary Physics, 56:4, 451-467, DOI: 10.1080/00107514.2015.1045193

Cluster Types

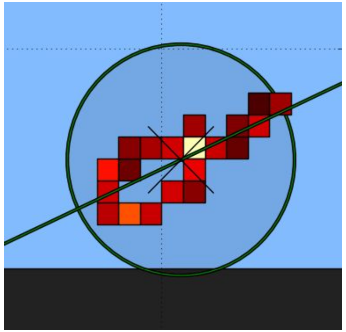
BOXY



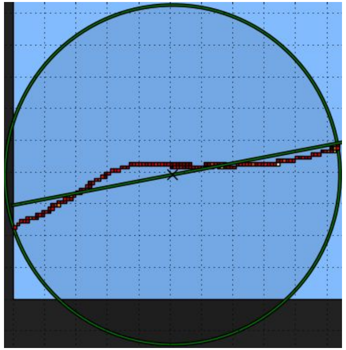
BRANCHER



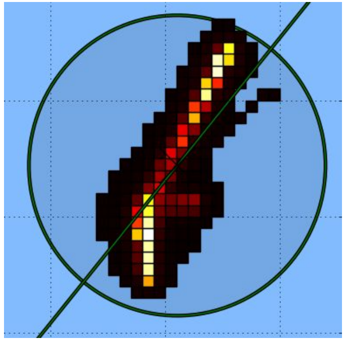
LOOPER



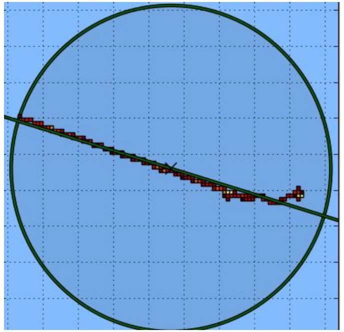
CURVED



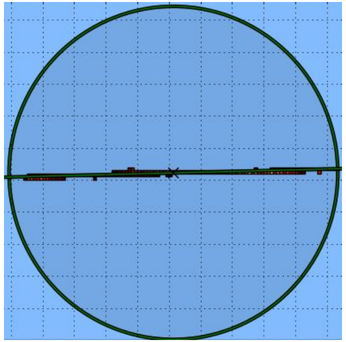
SLUG



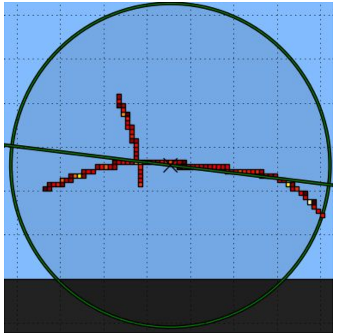
SW



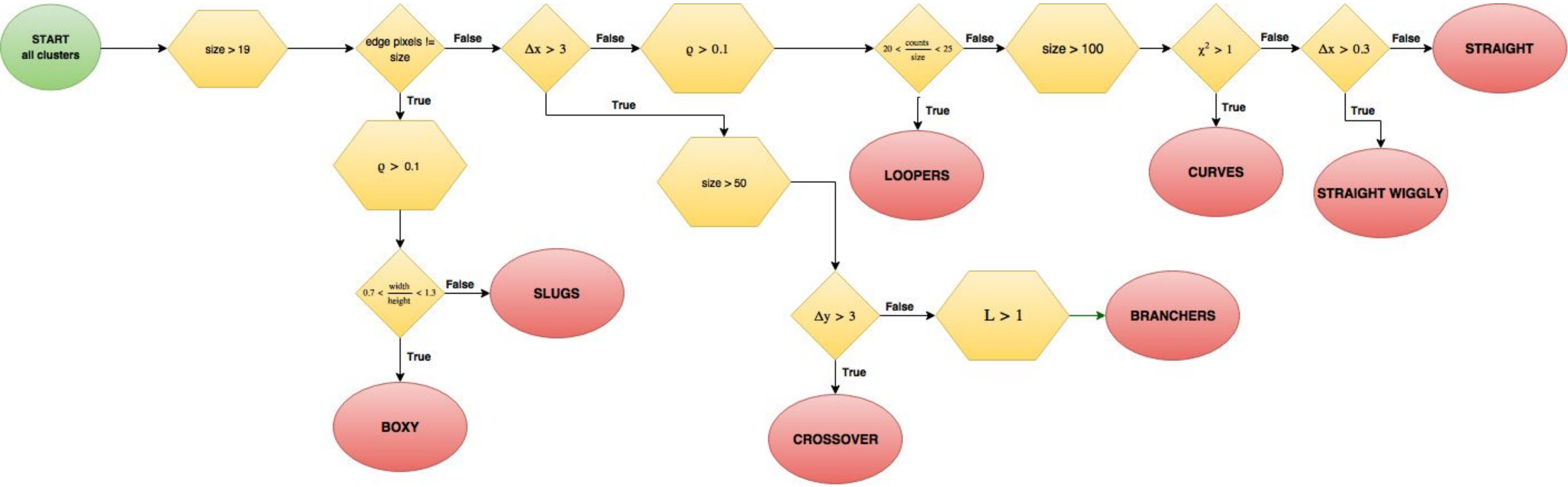
STRAIGHT



CROSSOVER



Cluster Sorting Algorithm



Results

- Efficiency from Report 1 (Jessica Flores & Ameir Shaa June 2016)

$$E_{eff} = 0.35$$

- Using new and improved algorithm,

$$E_{eff} = 0.85$$

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

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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

[1] S. Bibb, C. Cooke, A. Evans, E. Ireland, F. Pomeroy, T. Whyntie MoEDALUpdate Presentation LangtonStar Centre, Queen Mary University of London, January 2015

Summary and Moving Forward

- The efficiency of the algorithm: $E_{eff} = 0.85$
- 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 ½)
    - 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)

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Cultural Experiences

For more details: Ameir Shaa, Stephanie Baines, Jessica Flores, *MoEDAL Project Report 2*, 5th August 2016

THANK YOU!

… Questions?