LDMX: Clustering Electrons and Pions in the Hadronic Calorimeter

Joseph Kaminski – SULI Intern

Cristina Mantilla – Supervisor

Fall SULI 2022

12/072022

LDMX Experimental Overview

- Detect dark matter in the sub-GeV mass range.
- Electron beam collides with target nuclei.
- Dark matter is produced via dark bremsstrahlung.
- Calorimeters are used to veto events in which dark matter is not produced.
- Ordinary particles shower inside the calorimeters.
- Reconstruct the mass of the original particle via "clustering."
- Develop an algorithm to build clusters in the HCal.

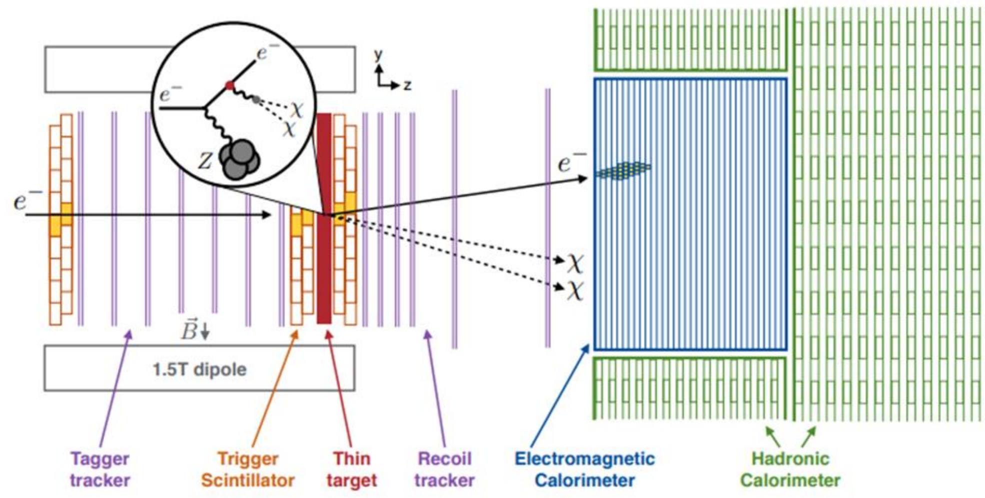
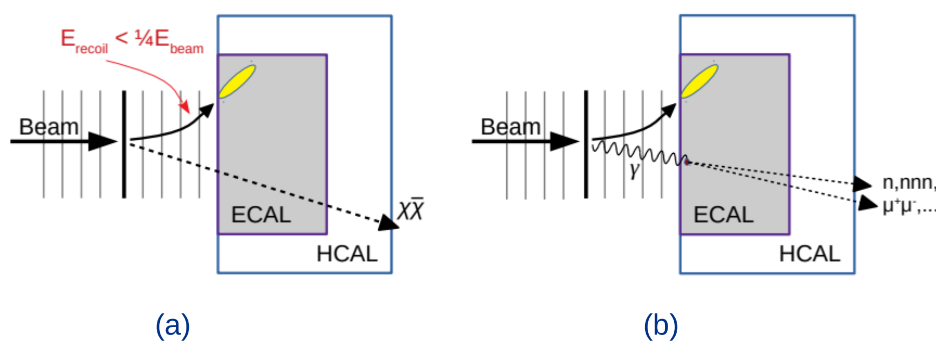


FIG. 1 (above): Schematic of the LDMX experimental apparatus.
FIG. 2 (below): Depiction of the processes in which dark matter is produced (a) or ordinary particles are produced (b) following the target collision.
Both images adapted from 'Light Dark Matter eXperiment,' by Åkesson et al., 2018.



Particle Gun Simulations

- Simulate a particle directly entering the HCal.
- The particle showers inside the HCal and deposits energy into the strips (hits).
- Simulation records data of hit energies and positions.
- Simulation parameters include type of particle, particle energy, gun position, particle beam width, and number of events.
- Single electron, two electrons, single charged pion.

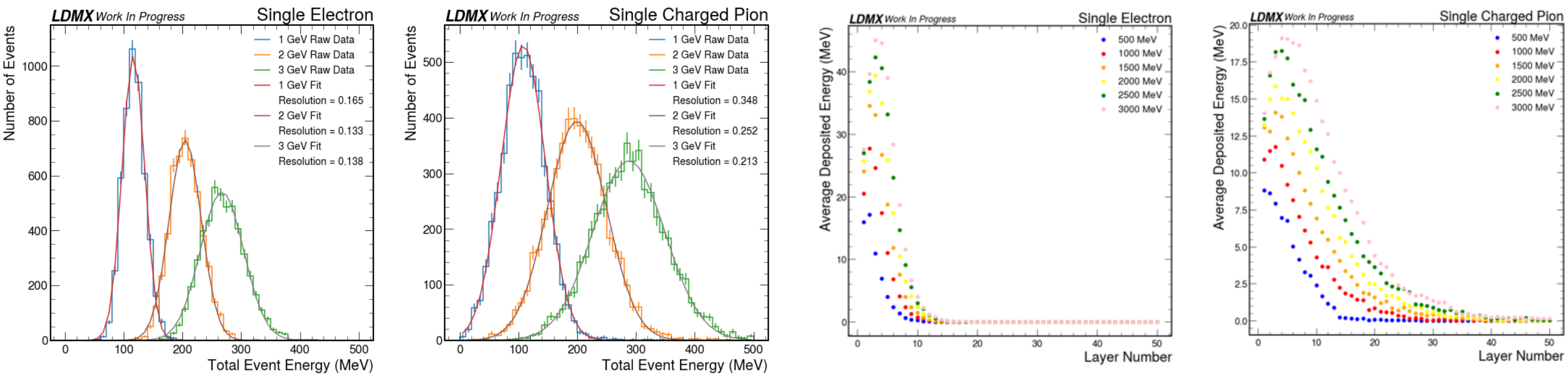


FIG. 3: Shower characteristics of electron and charged pion simulations.

Cluster Building Algorithm v2_5

- 2d Clustering:

- Combine the energies and positions of recorded hits in a single layer.

- Start with “seed hit, search neighboring strips for additional hits.

- Merge 2d clusters within a layer.

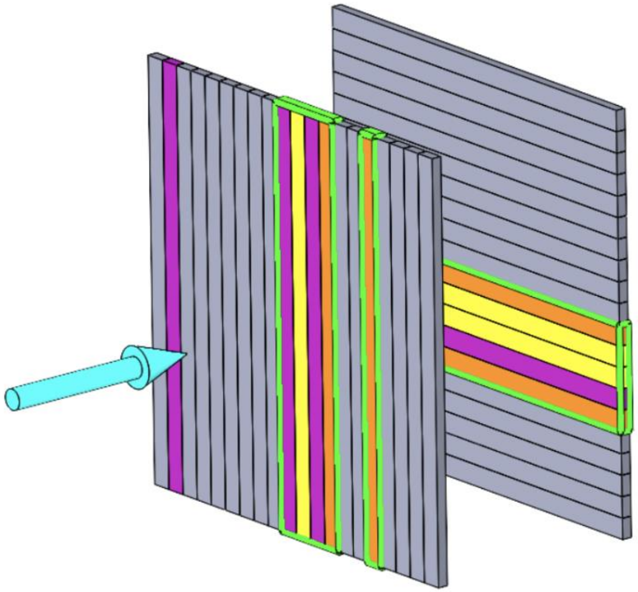


FIG. 4 (left): Illustration of simple clustering by Jonathan Rositas. Two HCal layers are shown. Yellow, orange, and purple strips indicate hits of various energies. 2d clusters are surrounded by the green lines. Image adapted from ‘Clustering High-Energy Neutron Hits in the LDMX Hcal,’ by Jonathon Rositas, 2022.

- 3d Clustering:

- Combine the energies and positions of 2d clusters from layer to layer.

- Begin with “shower max,” search neighboring layers for additional 2d clusters.

	Cluster Parameter	Value used in v2_5
(1)	2d Cluster Minimum Seed Energy	0.1 MeV
(2)	2d Cluster Minimum Neighbor Energy	0.01 MeV
(3)	2d Cluster Maximum # of Neighbors	4 Strips
(4)	2d Cluster Maximum x-y Distance	100 mm
(5)	2d Cluster Maximum x-y Merge Distance	100 mm
(6)	3d Cluster Minimum Seed Energy	4.0 MeV
(7)	3d Cluster Minimum Neighbor Energy	0.2 MeV
(8)	3d Cluster Maximum x-y Distance	1000 mm

TABLE I (above): Table containing all parameters used in the cluster algorithm version v2_5.

Single-Electron Performance

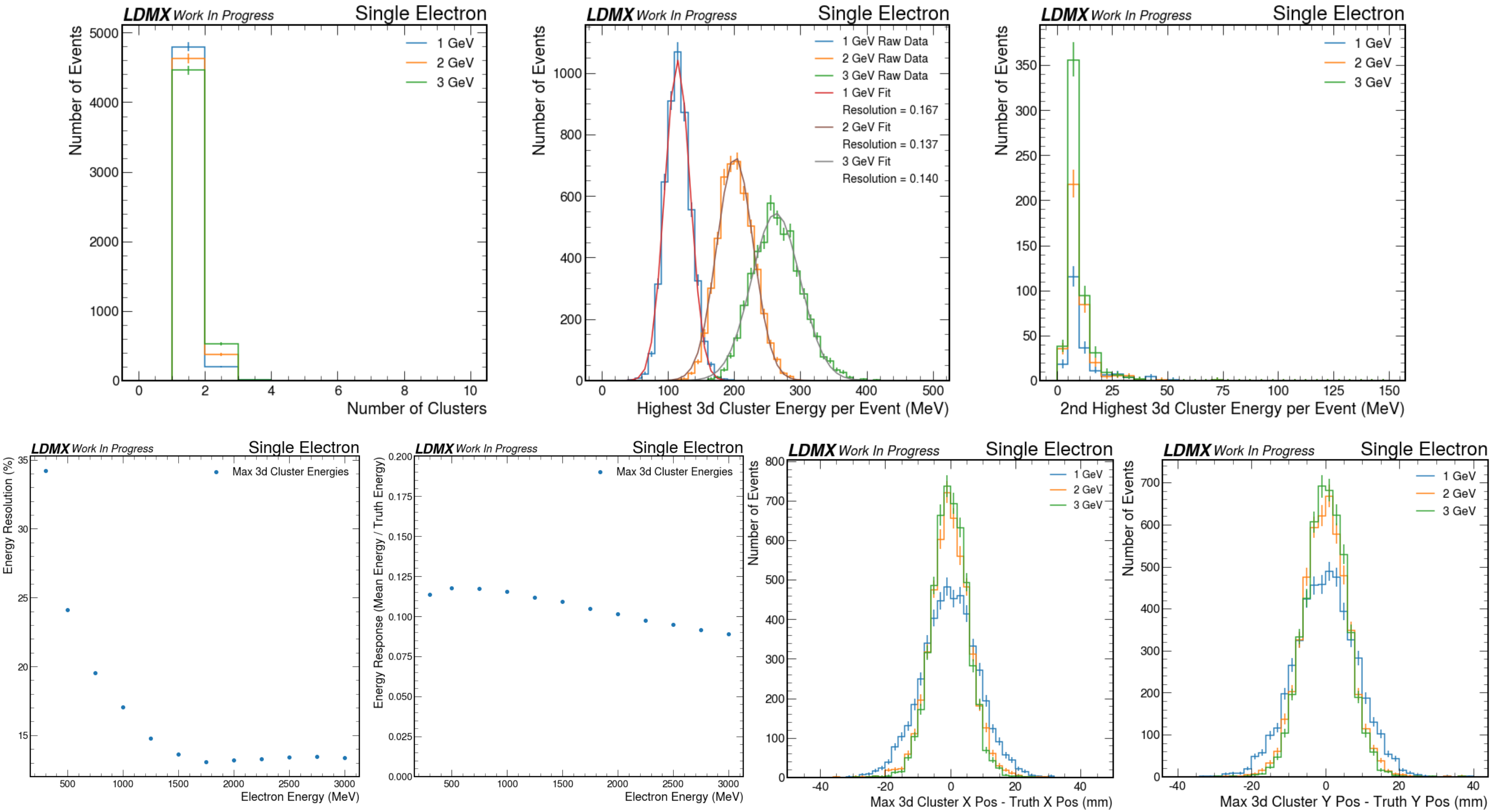


FIG. 5: Main results representing the performance of the algorithm on single-electron events. Starting on the left, the top three plots depict the number of 3d clusters per event, the energy of the highest energy 3d cluster per event, and the energy of the second highest energy 3d cluster per event. The bottom four plots depict energy resolution, energy response, and x-y position response, from left to right.

Two-Electron Performance

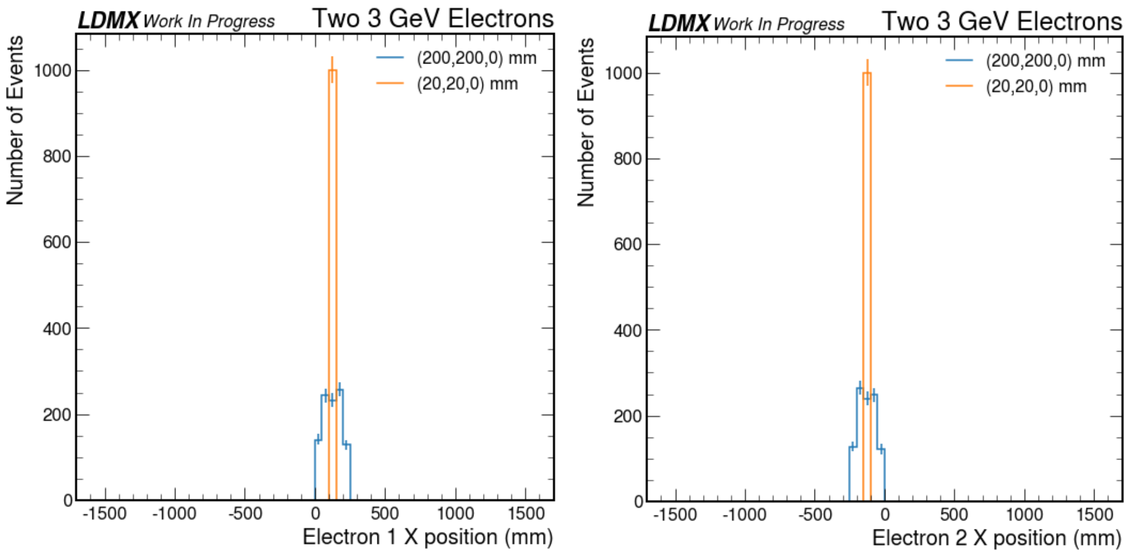
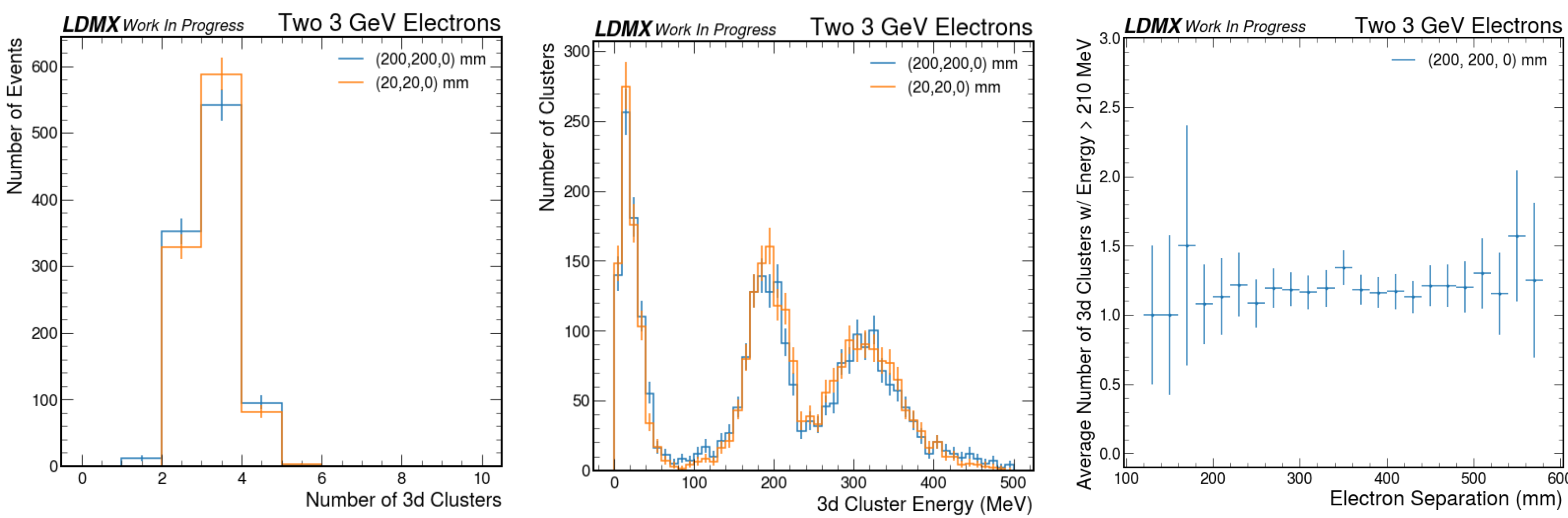


FIG. 6: Main results depicting the algorithm’s performance on two-electron events. The two plots on the left show the recorded hit positions of the two electron guns in the events for reference. From left to right, the bottom three plots below depict number of 3d clusters per event, all 3d cluster energies, and average number of 3d clusters with energy > 210 MeV against separation.



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Single-Charged-Pion Performance

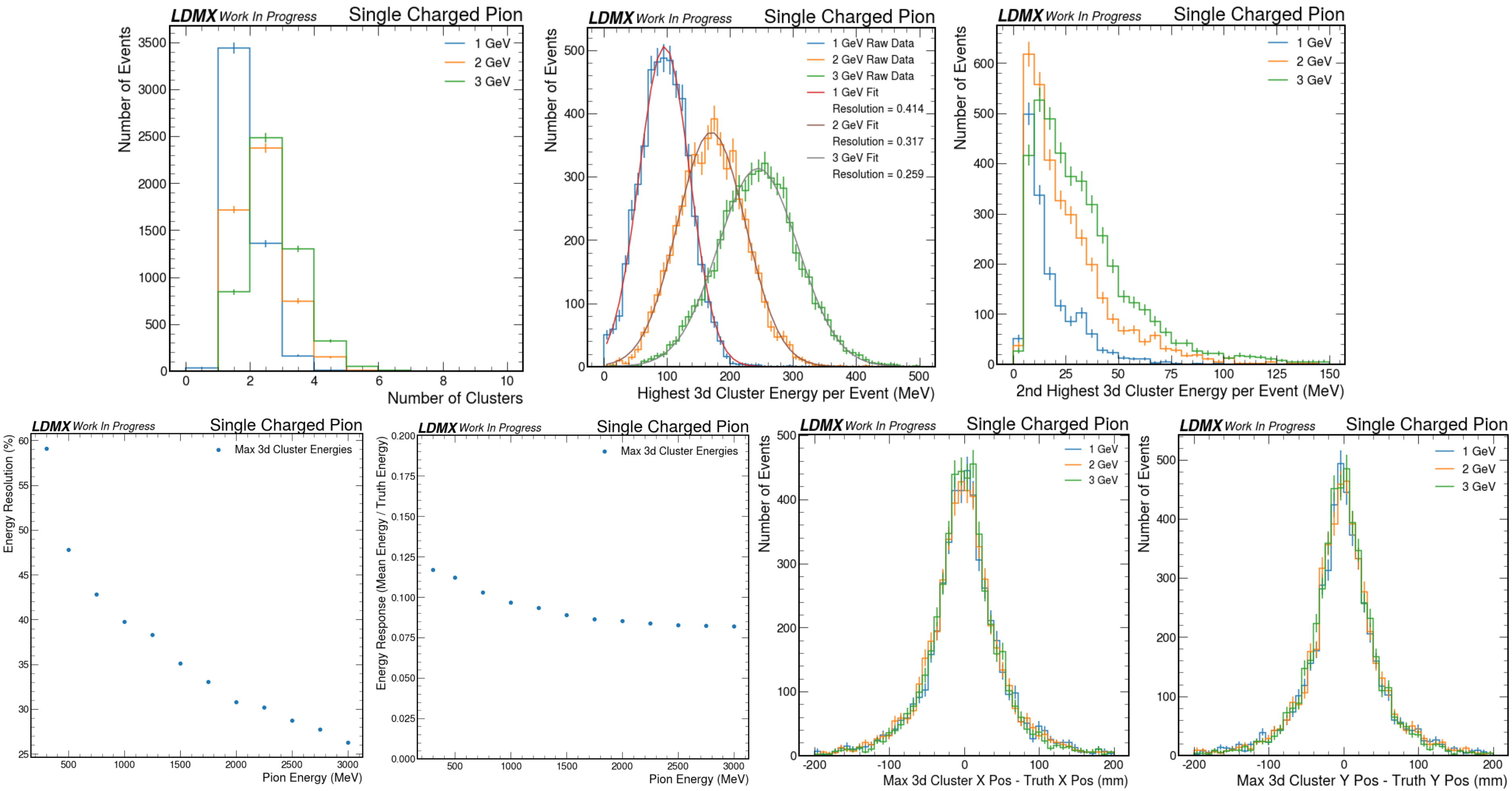

FIG. 7: Main results from the algorithm's test on single-charged-pion events. On top, we see more events with multiple 3d clusters being formed, and additional clusters feature higher energy than those of single-electron events. On bottom, the energy resolution is significantly higher for the pion, the energy response is not linear, and the position response features much higher resolution.

Conclusion

- The algorithm performed well on single-electron events.
- Too few simulations to reach conclusions on the algorithm's performance on two-electron events.
- The algorithm struggles to fully reconstruct pion showers.
- New algorithm version to improve performance on pion events.

Acknowledgments

Thank you to Cristina Mantilla, Christian Herwig, and Nhan Tran for their guidance and assistance of my work throughout the fall. They constantly put me in positions to expand my scientific and communicative skills.

Also, thank you to Fermilab for offering the opportunity for me to participate in SULI and grow as a physicist.

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