Using GPGPU Computing to Extend the Search for New Physics at the Large Hadron Collider

V. Halyo, P. LeGresley, P. Lujan
Princeton University

Triggers in High-Energy Physics

High-performance computing is a critical part of the CMS and ATLAS experiments at the Large Hadron Collider (LHC). In particular, the trigger system is especially demanding and an opportunity for GPGPU computing to extend the capabilities of the LHC. The trigger system is responsible for reducing the 40 MHz collision rate to a data rate that can be stored and processed (approximately 100 kHz), by selecting events containing interesting physics processes. In CMS (and similarly at ATLAS), it is implemented as a two-stage system:

- Level-1 (L1) Trigger
- High-Level (HLT) Trigger

The high-level trigger (HLT) performs a nearly full reconstruction of the event, and must do so in a very limited amount of time. A particularly demanding part of the reconstruction is tracking: reconstructing the tracks of the charged particles from the hits observed in the tracker.

In the CMS HLT, tracks are reconstructed regionally using the Combinatorial Track Finder (CTF). A trajectory is constructed from a seed of three hits in the inner layers of the tracker, and then propagated through the detector; at each layer, compatible hits are then attached and fit to the trajectory. However, as the LHC performance continues to increase, the number of hits increases, and so the number of possible combinations increases greatly, making this very computationally expensive to run.

New Physics with Displaced Tracks

In order to reduce the processing time at the HLT, only tracks produced close to the interaction point are reconstructed, as these account for the vast majority of events observed at the LHC. However, a wide variety of models exist which predict new physics in which particles are produced at a significant displacement from the interaction point. New physics following these models may therefore be missed by the current trigger.

Currently, in the CMS HLT, only the bold layers can be used for seeding a track...

...and the track’s point of closest approach must be within 0.5 cm of the primary vertex (green circle).

Highly-displaced tracks (such as the example in blue) will thus not be reconstructed!

In this study, we propose a new tracking algorithm which can reconstruct the tracks in the whole event, reducing the computational cost, and creating the opportunity for new triggers to detect previously-unexplored physics.

See our paper in JINST 8 P10005 (2013) for more information on displaced jet triggers.

The Hough Transform

The Hough transform algorithm was originally developed for image analysis applications, but has become popular in tracking applications as well, instead of operating locally, like the combinatorial track finder, it looks at the event as a whole to reconstruct tracks.

Below is an example of the Hough transform algorithm applied to a simulation of 500 curved tracks.

Original simulated hits

After the Hough transform is applied, the reconstructed tracks correspond to maxima in the parameter space.

$q/p$

Unlike the current CTF algorithm, the Hough transform’s running time is linear in the number of hits, and is inherently highly parallelizable. This gives us the opportunity for greatly improved performance using a GPGPU implementation.

Finding Displaced Jets and Black Holes

In addition to reconstructing individual tracks, the Hough transform can be used to find displaced vertices in the event, thus extending our physics reach to entirely new classes of events. Here is an example in an event with four simulated displaced jets.

When the Hough transform is applied, the tracks again correspond to maxima in the parameter space. We can then apply the Hough transform a second time to identify the vertices formed by the tracks!

Conclusions

The Hough transform used in conjunction with GPU computing offers a way to:

- Reconstruct all tracks in an event in a single step, thus helping to counter the effects of increasing luminosity.
- Extend the physics reach of the trigger by allowing us to search for models not practical with the current trigger.

Studies on applying this technique to a realistic CMS simulation are currently under way.

For more information, see our paper: arXiv:1309.6275 (accepted by NIM)

New Physics Models

Many new physics models predict such a signature, including:

- Hidden valley models with long-lived neutral particles (the figure at right shows an example with $H \to XX \to 4$ jets, where $X$ is a long-lived neutral boson)
- Displaced black holes
- Boosted jets
- R-parity-violating SUSY models with long-lived neutralinos
- $Z'$ models with long-lived neutrinos

See our paper in JHEP 01 (2014) 140 for more physics applications in the displaced b-jet channel.

GPU Implementations

GPU implementations of the Hough transform for performing tracking have been created and tested, and perform more than 10 times better than a comparable CPU implementation!