CATEGORY: COMPUTATIONAL PHYSICS - CY09

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GPU TECHNOLOGY CONFERENCE

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

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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 an especially demanding environment 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 Hz), by selecting events containing interesting physics processes. In CMS (and similarly at ATLAS), it is implemented as a two-stage system:

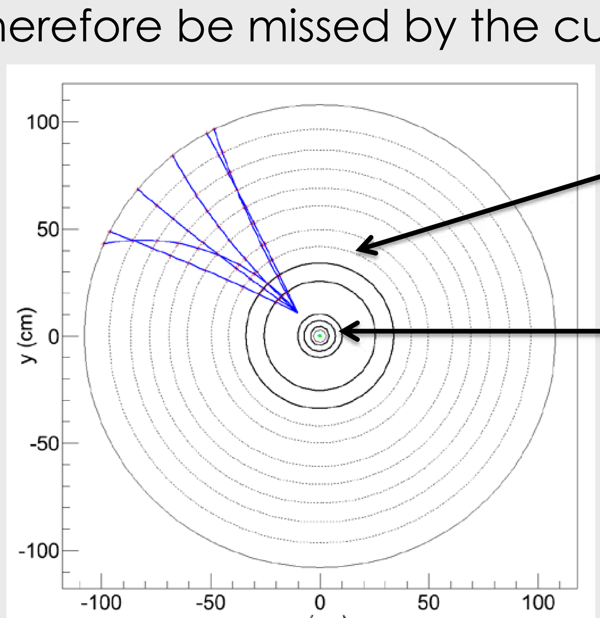
40 MHz Collision Rate → **Level-1 Trigger (L1)** → **100 kHz after L1** → **High-Level Trigger (HLT)** → **100 Hz Final Rate**

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!

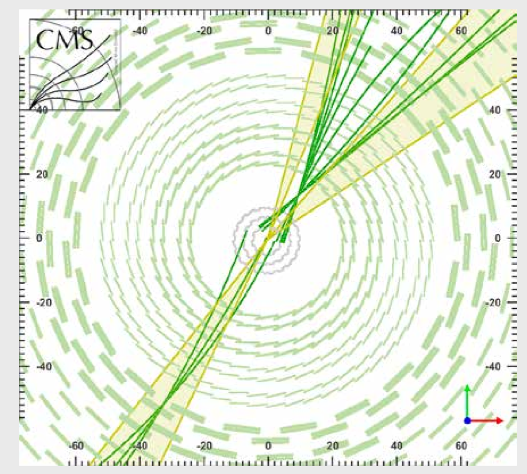
In this study, we propose a new tracking algorithm which can reconstruct the tracks in the whole event, reducing the computational cost, and creating the opportunity for **new triggers** to detect previously-unexplored physics.

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

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 → XX → 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



CMS simulation (courtesy A. Zuranski)

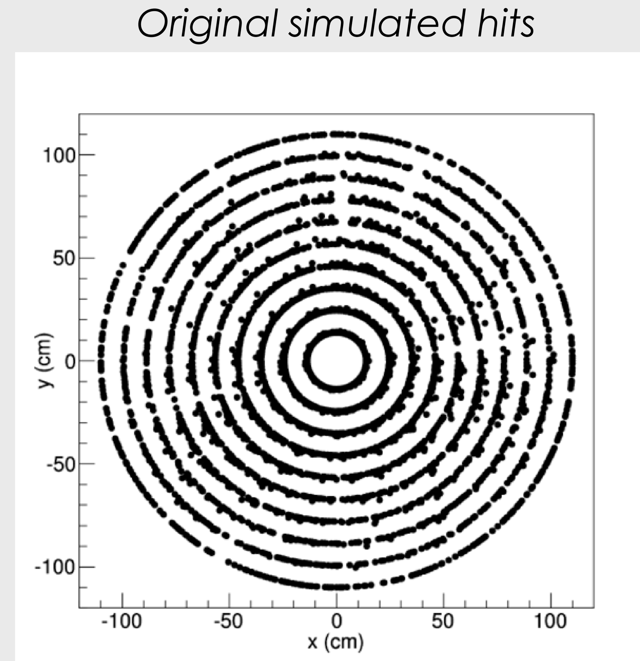
See our paper in *JHEP* 01 (2014) 140 for more physics applications in the displaced b-jet channel

The Hough Transform

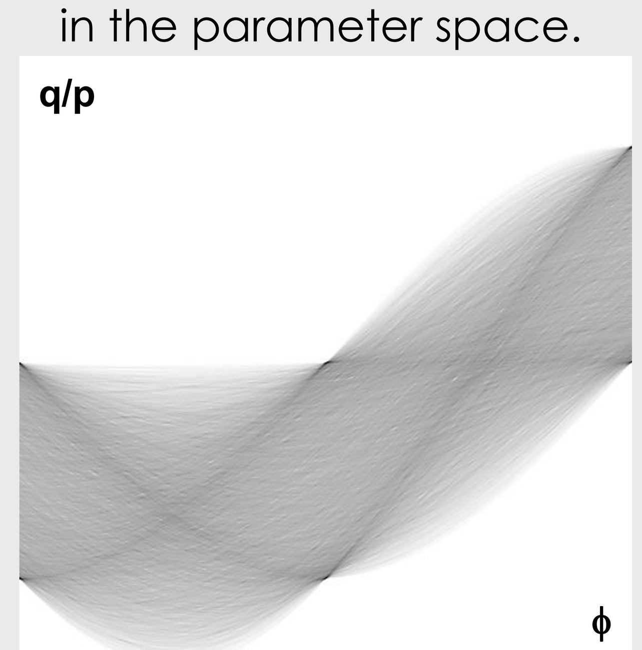
The **Hough transform algorithm** was originally developed for image analysis applications, but has become popular in tracking applications as well. Instead of operating locally, like the combinatorial track finder, it looks at the **event as a whole** to reconstruct tracks.

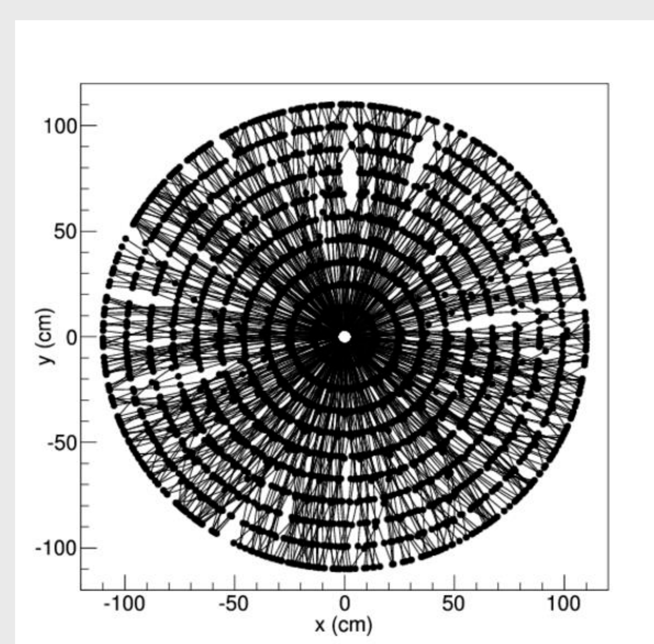
Below is an example of the Hough transform algorithm applied to a simulation of 500 curved tracks.

Original simulated hits



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



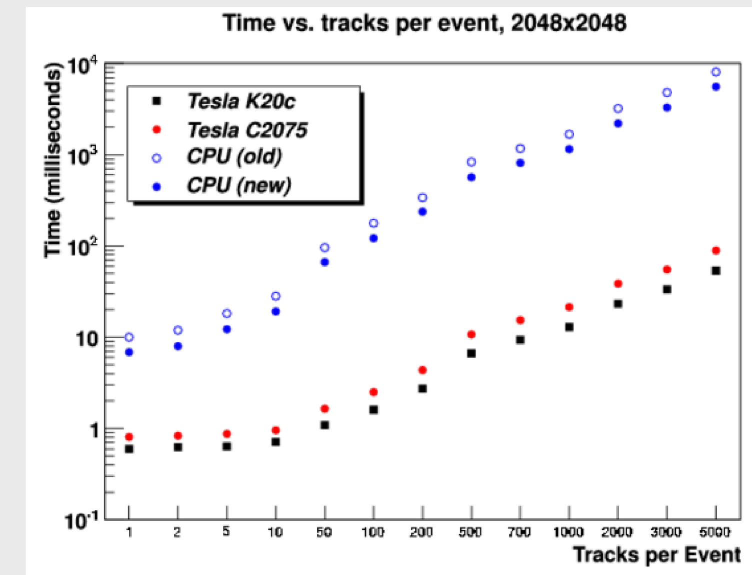


Final reconstructed tracks

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.

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!



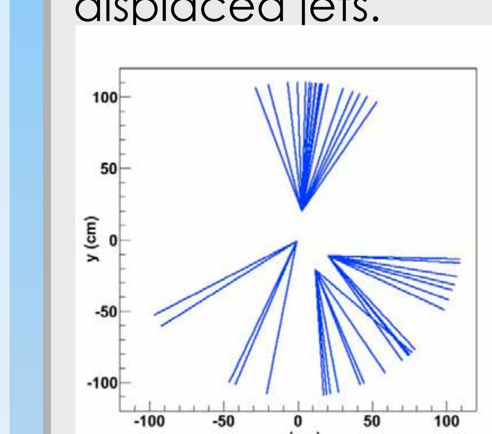
Black: Tesla K20c
Red: Tesla C2075
Blue: Intel Core i7-3770 (two implementations)

C2075: 448 cores @ 1.15 GHz, 6GB RAM
K20c: 2496 cores @ 706 MHz, 5GB RAM

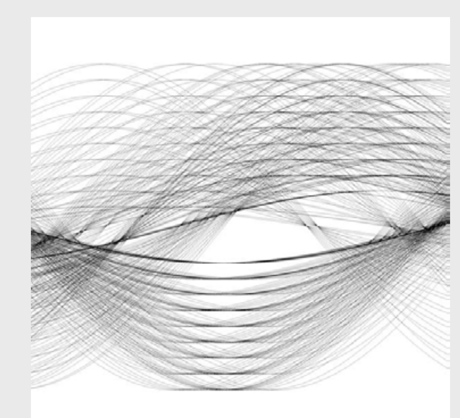
See arXiv:1310.7556 (submitted to JINST) for more about GPU and MIC implementation of these algorithms

Finding Displaced Jets and Black Holes

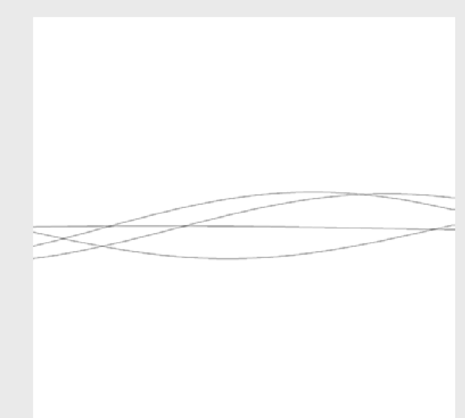
In addition to reconstructing individual tracks, the Hough transform can be used to find **displaced vertices** in the event, thus extending our physics reach to entirely new classes of events. Here is an example in an event with four simulated displaced jets.



Original simulated event



The first Hough transform finds the tracks…



Now, a second Hough transform finds the 4 vertices in the parameter space!

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)