IRIS-HEP Fellows Program Project Proposal

Displaced Vertex Finder on GPUs for LHCb

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1. Project Summary

1.1. High-level triggers at LHCb

Currently, the LHCb[1] detector is capable of reading out at a full bunch crossing rate of 30 MHz, or a maximum data rate of 40 Tbit/s. To be able to obtain information about the events of interest for LHCb analysis, it is necessary to significantly reduce the data rate, which is implemented by two software stages. The first stage, called HLT1, performs fast track and vertex reconstruction and selection of *pp* collision events at the LHCb based on single- and double-track displaced vertices and saves the data to a buffer. In the second step, HLT2, the detector is aligned and calibrated in near-realtime, and the remaining events are subjected to offline track reconstruction, full particle identification, and track fitting. This approach results in a total output data volume of 80 Gbit/s. In Run 3, HLT1 was improved by implementing it on the GPU, which allowed for parallel event processing.[2]

The goal of this project is to build generic vertex finder for displaced vertices and provide generic vertices formed by VELO tracks: their positions, uncertainties. As part of the IRIS-HEP Fellows Program 2024, an algorithm with the main stages of building such vertices was implemented, which will be improved during this project.

1.2. Reconstruction Generic Displaced Vertices in LHCb

Many New Physics scenarios posit the existence of new long-lived particles (LLPs) that could help explain long-standing puzzles in physics, such as the origin of Dark Matter. Such particles can be produced in high-energy proton-proton collisions at the Large Hadron Collider and can be detected by the LHCb detector, which has a unique sensitivity to particles with masses of the order of GeV. The LHCb detector is a single-arm spectrometer that is very well equipped in the forward part, which allows it to detect signal from the decay of LLP into Standard Model particles with high accuracy and excellent vertex reconstruction. However, to do this effectively, a specific algorithm is needed that can quickly identify collisions where these long-lived particles appear.

In this work, we can distinguish two types of vertices: Primary Vertices (PV) and Generic Displaced Vertices (GDV). PVs are located close to the beamline, the tube where protons are accelerated, and can be considered as points of interaction of these protons in the collider or decay of short-lived particles. GDVs are located at a distance from the beamline and are therefore considered as candidates for LLP decay vertices.

As part of the IRIS-HEP Fellows Program 2024, a GDV search algorithm was developed and implemented in several stages:

- **Search for vertices by pairs of tracks:** We consider every two tracks in VELO detector[3] in the event and calculate the distance between them. If they are close to each other according to the criterion χ^2, we build a so-called **Seed Vertex**, which is a candidate for a real GDV.

- **Adding other tracks to the found two-track vertices:** All other tracks are checked to see if they fit to the built Seed Vertex. For this purpose, the distance between the vertex and each other track in the event is measured. If they are close according to the same χ^2 parameter, then these tracks are assigned to the selected vertex.
- **Vertex merging:** If several vertices are close enough to each other, they can be treated as one. Accordingly, at this stage, the distances between all constructed vertices are calculated, and if the proximity is sufficient, a new merged vertex is constructed according to the χ^2 criterion. Thus, the total number of GDV candidates is reduced.

1.3. Improvement of the Displaced Vertex Finder

To further improve the efficiency of reconstructing displaced vertices, it is necessary to add the calculation of errors in the form of covariance matrices. Each track used in the algorithm has its own error values for the x, y, and z coordinates and slope angles, which can be used to improve the positioning accuracy of the constructed vertex. The calculation of eigencovariance matrices for vertices will be implemented at each stage of the algorithm. As a result, we get a set of vertices with more accurate positions and errors that can be used in further analysis.

The next important step to optimize the algorithm is to define the "displacement" criterion for the vertex and the corresponding constraints on the parameters such as coordinates, distance to the beamline, number of tracks, etc. It is also important to investigate the optimal parameters for the vertex merging, such as the maximum distance when we can consider two vertices as one.

Once the algorithm is ready, it will need a fast CUDA implementation to run online on the LHCb GPU farm. This can be done with Allen, which is an HLT1 application on GPUs that will allow running the algorithm on both CPUs and GPUs. In the further physical analysis, the data obtained from GVFinder can be used to search for exotic vertices. Additionally, with the help of this algorithm, a trigger selection will be developed. Such a trigger line will dramatically increase the sensitivity for inclusive and many exclusive searches for LLPs at once.

2. Timeline

- **Week 1**: Study the structure of existing triger algorithms at the HLT1 and HLT2.
- **Week 2-4**: Implementation of the covariance matrices calculation at each stage of vertex construction, and definition of the "displacement"criterion.
- **Week 5-10**: Implementing of a ready Displaced Vertex Finder algorithm on the GPU using CUDA tools
- **Week 11**: Testing the algorithm on Monte Carlo models with SM and BSM physics simulations that generate displaced vertices
- **Week 12**: Preparation of the final presentation for the project.

References

[1] The LHCb Collaboration et al 2008 JINST 3 S08005.

[2] arXiv:1912.09161, Allen: A high level trigger on GPUs for LHCb

[3] R. Aaij et al., LHCb Velo Upgrade Technical Design Report