Development of high-performance reconstruction algorithms for detecting long-lived particles

Volodymyr Svintozelskyi[1]

[1]Taras Shevchenko National University of Kyiv

1 Project Summary

1.1 Introduction

The LHCb detector [1] at CERN is currently being prepared for Run 3 of the LHC. It is due to begin data taking in 2022 at an instantaneous luminosity of $L = 2 \times 10^{33} cm^{-2} s^{-1}$, corresponding to an average of around 6 proton–proton (pp) collisions per LHC bunch crossing. At this luminosity, the rates of beauty and charm hadrons, which are of interest for most LHCb analyses, reach the MHz level in the LHCb detector's geometrical acceptance [2]. The majority of them decays into fully hadronic final states. Thus, efficiently reducing the output data rate requires finding charged particle trajectories (tracking) in real-time to be used at the first level of the selection procedure (trigger) [3].

Event selection relies on two software stages. In the first stage, called HLT1, events are primarily selected using inclusive one- and two-track-based algorithms, in some cases requiring the track to be identified as a muon. In the second stage, called HLT2, the detector is aligned and calibrated in near-realtime and the remaining events undergo offline-quality track reconstruction, full particle identification and track fitting. Because of the high signal rate, HLT1 does not only classify bunch crossings (events) as interesting or uninteresting. Rather in most cases HLT1 identifies a decay of interest and associates it to one of the reconstructed pp collisions [3].

The entire charged particle reconstruction (tracking) system of the LHCb detector was renewed as part of the last upgrade. In particular, the tracker placed downstream of the LHCb dipole magnet is replaced by a scintillating fibre tracker (SciFi) described in detail in Ref. [4]. The SciFi consists of three stations (T1, T2, T3), each composed of four layers of stacked scintillating fibres. An algorithm relying solely on the information provided by this tracker is called Hybrid seeding. It allows an efficient reconstruction of tracks from particles with momenta down to $1.5 GeV/c$. The track segments reconstructed by this algorithm are used as seed for other pattern recognition algorithms in LHCb [5]. During the previous run of LHCb (Run2) the Hybrid seeding algorithmos was designed to be executed within HLT2. A new and optimized version of this algorithm is being implemented to be executed in the Allen framework [3] using the upgraded HLT1 farm, based on about 500 GPUs (NVIDIA RTX A5000), and exploting the high level of parallelization.

1.2 Purpose of the work

Due to the use of improved detectors and to a planned faster readout in future LHCb upgrades and, as a result, striker timing constraints, the use of current hardware solutions become impossible. This leads to a requirement of implementing tracking algorithms within new heterogeneus architectures, such as FPGAs and/or GPUs, that also will satisfy new striker power constraints.

The student will work on the development and implementation of particle reconstruction algorithms using GPUs and/or FPGAs, as well as on the real-time processing of massive data.

Long-lived particles (LLPs) show up in many extensions of the Standard Model, yet leave elusive signals in most current searches, due to their very displaced vertices. Decay products of the LLPs can originate outside the Velo acceptance, then escaping to detection. The present HLT1 version of LHCb do not use tracks which are produced downstream of the magnet due to timing constraints, then implying a large inefficiency for LLPs. One of the main challenges in the track reconstruction is to deal with the large amount of hits in the central scintillator tracker, the SciFi detector. A dedicated algorithm is being developed to cope with the large data output and the student will work on its optimization to be executed in GPUs and/or FPGAs. The use of new ML techniques on heterogeneous architectures may be exploited. The aim is to achieve a better and faster version of the algorithm to be executed in HLT1.

The knowledge acquired during this work will be interesting also for industrial and real-life applications. FPGAs are for instance being used in medical imaging systems, satellites and other space areas.

1.3 Timeline

The anticipated duration of the project is a three-month period, June–Sep 2022, at 100% FTE. Supervision of this project will be provided by Arantza Oyanguren (IFIC - University of Valencia/CSIC, Spain). A timeline with deliverables is provided below.

Week 1-2

Study the documentation of existing GPU based algorithm Allen, understand the structure and become familiar with its usage. Investigate the exiting tracking algorithms like Hybrid seeding [5].

Week 3-5

Begin with optimizing an existing Allen software for GPU based system. Start with the implementation of tracking algorithms within an FPGA-based infrastructure.

Week 6-8

Start the simulation and hardware tests of developed algorithms for the FPGA platform. Work on fixing the bugs.

Week 9-10

Prepare structured documentation for the developed modules. Create and present the final presentation for the project.

References

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