Studies of new trigger lines, dedicated to long-lived particle detection at the LHCb experiment

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1 Project Summary

1.1 Introduction

The Standard Model of particle physics (SM) is presently the established theory, known for its theoretical self-consistency and accurate predictions of experimental outcomes. However, it does have certain limitations. For instance, the SM fails to account for the existence of dark matter and the origin of neutrino masses. As a result, scientists have proposed extensions and alternative models, collectively referred to as New Physics (NP) or beyond the Standard Model (BSM), which involve particles that could potentially be detected in collider experiments. Typically, these theoretical new particles are assumed to decay promptly, influencing the design of detectors and reconstruction techniques in recent years. Nonetheless, some theoretical mechanisms suggest that these particles could have long lifetimes. In such scenarios, these long-lived particles (LLPs) can travel a considerable distance from the primary vertex (PV), exceeding the detector's spatial resolution. [1]

The development of new algorithms and software high level trigger lines at the LHCb experiment is crucial [2] to detect these new particles during the Run3 of the LHC proton-proton collider, and it is the main scope of this project.

1.2 LHCb detector

The LHCb detector [3] at CERN has been upgraded in the last years and is currently being commissioned for the Run 3 of the LHC. At present, it is taken data at an instantaneous luminosity of $L = 2\times10^{33} cm^{-2}s^{-1}$, 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 [4]. 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) [5] A large effort has been done in the previous years to achieve this, allowing to remove the hardware trigger selection during the Run3.

The present LHCb 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 [5]. The updated HLT1 trigger stage is implemented within the GPU farm, consisting of about 500 NVIDIA RTX A5000 cards, and exploiting the high level of parallelization. The entire charged particle reconstruction (tracking) system of the LHCb detector has been then renewed. In particular, the tracker placed downstream of the LHCb dipole magnet has been replaced by a scintillating fiber tracker (SciFi) described in detail in Ref. [6]. The SciFi consists of three stations (T1, T2, T3), each composed of four layers of stacked scintillating fibers. The use of GPUs in HLT1 has allowed the development of new algorithms which are not using the seeds from the first tracker for reconstruction, but just the ones from the SciFi.

1.3 Long-lived particles at LHCb

Decay products of the LLPs originate outside the first tracker volume (the VELO detector), therefore they don't leave hits inside it. This usually leads to the impossibility of reconstructing such tracks with traditional algorithms, optimized for so-called "Long" tracks, or tracks with signals in VELO and SciFi.

The brand-new downstream algorithm (!1095) was recently added for downstream track reconstruction (tracks, with hits in both UT and SciFi), and the corresponding trigger lines are currently under development. Together, this opens a lot of opportunities for studying long-lived particles at LHCb.

In addition, the development and optimization of dedicated trigger lines, based on the downstream algorithm, is crucial for the commissioning of the new UT detector that has been recently installed at LHCb.

1.4 Purpose of the work

The main goal of the current project is optimization of the two-track trigger lines for long-lived particles, that are based on tracking information from both SciFi and UT. These lines are based on the topologies of SciFi seeds coming from standard long-lived particles, such as the strange Λ^0, produced at the interaction point, as well as K_s. The lines may use either "fast-vertexing" technique, which involves a selection of two tracks by set of cuts, or a full scale fitting procedure. The corresponding analysis may be done with usage of AI techniques.

The goal of optimization is to reduce background as well as output ghost rate of the trigger lines. Several studies relying on MC simulations will be performed to understand the variables of interest that may be used to select the events.

The significant limitation of the development of new trigger lines is coming from the output trigger rate constraints, since the SciFi occupancy is huge, which creates a lot of two-track combinations. Another limitation is the throughput of the whole HLT1 system, which is dictated by the slowest algorithm in sequence. This also applies constraints on size of corresponding Neural Networks, that may be used for particle selection. However, a high level of parallelism and the proper use of the shared memory may improve the throughput.

The physics performance and capability of new trigger lines will be verified using specific decay channels from both SM transitions and new processes, such as the dark bosons H', in $B^+ \to K^+ H'$ with $H' \to \mu^+\mu^-$. In addition, the optimized trigger lines will be tested on real data from LHCb Run 3.

The results of students work will be properly evaluated at LHCb Working Package meeting by experts in the field.

1.5 Timeline

The anticipated duration of the project is a 12 week period, June–Sep 2023, at 100% FTE. A timeline with deliverables is provided below.

- **Week 1-2:** Study the implemented long-lived particle's reconstruction algorithms. Look for optimization possibilities.
- **Week 3-5:** Optimization of trigger lines, studying the advantage of AI model in particle selection, based on downstream tracks, as well as it's limitations.
- **Week 6-8:** Implementation of developed algorithms using Allen - CUDA-based framework for HLT1 reconstruction. Conducting the throughput studies of developed solutions. Validation of the code on different architectures: CPU, GPU. Preparation of the corresponding merge request.
- **Week 9-10:** Validation of the developed trigger line algorithms using specific decay channels. Conducting tests with real data from LHCb Run 3. Presentation at LHCb Working Package meeting.
- **Week 11-12:** Preparation of structured documentation for the developed code. Creation of the final presentation for the project.

References

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