Study of the performance 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 the current established theory, being theoretically self-consistent and having predicted experimental results with high precision. It nevertheless has several limitations. For instance, the SM is unable to predict the existence of dark matter and the origin of neutrino masses. This has motivated theorists to propose New Physics (NP) extensions and alternative models involving beyond the Standard Model (BSM) particles that may be measurable in collider experiments. In general, these hypothetical new particles are assumed to decay promptly, which has impacted the design of detectors and reconstruction techniques over the last years. However, some theoretical mechanisms suggest that these particles may have large lifetimes. In these cases, the long-lived particles (LLPs) can fly a significant distance from the primary vertex (PV), larger than the spatial resolution of the detector. [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 $L = 2 \times 10^{33} cm^{-2} s^{-1}$, 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 [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 new farm, based on about 500 GPUs (NVIDIA RTX A5000), 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 acceptance (the VELO detector), then usually escaping to detection if tracking algorithms are based on VELO seeds. The present HLT1 version of LHCb is being modified to use tracks which are produced downstream of the magnet, then increasing the efficiency for LLPs. The new algorithms that use either SciFi only or SciFi and UT (the second tracker) data are being studied and will need some optimizations.

1.4 Purpose of the work

The main goal of the current project is the development of the trigger lines for long-lived particles, that will use the output of recently developed reconstruction algorithms, using either SciFi alone or SciFi and UT data as input. These lines will be based on the topologies of SciFi seeds coming from standard long-lived particles, such as the strange Λ^0, produced at the interaction point. 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. The SciFi seeds will be divided into the ones that are used for long-tracks reconstruction, and the ones that are not used. Another limitation is the throughput of the whole HLT1 system, which is dictated by the slowest algorithm in sequence. A high level of parallelism and the proper use of the shared memory will be included to improve the throughput. Another important point is the physics performance and the capability of the trigger lines for LLPs detection. The student will use some AI-powered algorithms, that may significantly increase the performance, always keeping under control the execution time. The physics performance 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 $H' \to \mu^+\mu^-$.

1.5 Timeline

The anticipated duration of the project is a three-month period, Dec–Feb 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 implemented long-lived particle's reconstruction algorithms. Look for optimization possibilities.
- **Week 3-5:** Development of new trigger lines, for tracks with no VELO hits, within existing constraints. Simulation of physics channels and study of the particle topologies.
- **Week 6-7:** Implementation of developed trigger line algorithms using Allen - CUDA-based framework for HLT1 reconstruction.
- **Week 8:** Validation of the developed trigger line algorithm using specific decay channels. Test within full LHCb stack.
- **Week 9-10:** Preparation of structured documentation for the developed modules. Creation of the final presentation for the project.

References

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