Trigger reconstruction algorithms at LHCb

Miguel Ramos Pernas
Universidade de Santiago de Compostela
miguel.ramos.pernas@cern.ch

COMCHA
October 10, 2018
Main computing topics at Santiago

- Reconstruction of muon and electron tracks for the LHCb Upgrade.
- Contributions to the design of the High Level Trigger (HLT).
- Work with GPUs:
  - Expensive fits
  - Reconstruction
- Involvement on the GRID Tier-2 (LCG.USC.ES) (1036 CPUs, 6 % of Tier-2 power at LHCb).

A lot of ideas to test (many of them already inplace) and some new ones after the results achieved by some of our new PhD/Master students and thanks to new incorporations to our team.
Despite the picture looks familiar, it is a complete new detector. I will focus on the sub-detectors of interest for this talk, and on the main changes.
The LHCb in the upgrade

Despite the picture looks familiar, it is a complete new detector. I will focus on the sub-detectors of interest for this talk, and on the main changes.

Move from strip to pixel silicon detector. Closer to beam.

Finer granularity. Less material.

Scintillating fibers, read out with SiPMs.

New electronics. Removal of one muon station.
The trigger in the LHCb Upgrade

- Higher luminosity is a big challenge for a forward spectrometer.
- Move to a full software trigger.
- Reduce the output bandwidth by selecting the parts of the event we want to persist.

LHCb 2015 Trigger Diagram

- 40 MHz bunch crossing rate

L0 Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures

- 450 kHz $h^\pm$
- 400 kHz $\mu/\mu\mu$
- 150 kHz $e/\gamma$

Software High Level Trigger

- Partial event reconstruction, select displaced tracks/vertices and dimuons
- Buffer events to disk, perform online detector calibration and alignment
- Full offline-like event selection, mixture of inclusive and exclusive triggers

12.5 kHz (0.6 GB/s) to storage

LHCb Upgrade Trigger Diagram

- 30 MHz inelastic event rate (full rate event building)

Software High Level Trigger

- Full event reconstruction, inclusive and exclusive kinematic/geometric selections
- Buffer events to disk, perform online detector calibration and alignment
- Add offline precision particle identification and track quality information to selections
- Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

2-5 GB/s to storage

Miguel Ramos Pernas

Trigger reconstruction algorithms at LHCb

(COMCHA, October 10, 2018) 3
The final structure of the LHCb trigger in the Upgrade has not been decided yet. However:

- No scenario with a hardware trigger is considered.

- Ideally we would have two levels:
  - HLT1: only reconstruction and general information from the subdetectors (occupancy), and simple PID.
  - HLT2: full reconstruction and particle identification. Apply the same tools/algorithms as in any offline selection.

- Depending on our final performance at HLT1, we might or not include a low-level software trigger.

In Santiago we are working in both HLT1, at reconstruction level, and HLT2, doing bandwidth studies of selections for decays of interest.
Contributions to HLT1

The timing of doing the VELO clustering at 30 MHz currently takes a very important part of the HLT1 overall timing.

In addition, more time is needed to extrapolate to the UT, a step where we would have already a nice precision on the (transverse) momentum $\mathcal{O}(15\%)$.

Boosting the algorithms is becoming a high priority at LHCb:

- Correctly adapt each algorithm to each physics case.

- Increase C++ performance in the code.

- Consider new computing resources: FPGAs, GPUs, ...
Matching Velo-UT tracks to Muon hits

**Low \( p_T \) physics**

- At Santiago we have a very big group to study strange decays, like \( K^0_S \rightarrow (\pi^0/\gamma) \mu^+ \mu^- \).

- \( K^0_S \) are produced with a very low angle with respect to the beam-pipe.

- Low-\( p_T \) algorithms are crucial to study these decays.

- In Run-II we profit from an algorithm that matches Velo-TT\(^1\) tracks to hits in the muon chambers.

- Serves as a simple muon-identification algorithm, that does not need the full Kalman-filter.

- It is currently being used to forward very low-\( p_T \) tracks (\( p_T < 500 \) MeV/c) with big chances of being muons (that otherwise would be omitted).

---

\(^1\)TT is a similar sub-detector to the UT, present in Run-I(I).
The algorithm in the Run-II

- Magnetic field is almost constant in $\hat{y}$, we can assume a “kink” concentrated in one point $z_f$, deflecting the particles in $x$.

- The position of $z_f$ is parametrized as a function of the slope of the VELO track $t_x$.

- The momentum is obtained from the VeloTT track, thanks to the remnant of the magnetic field inside the TT.

- Extrapolation is done to the muon chambers looking for hits, fitting them, and requiring a condition on the $\chi^2$ of the fit.
The algorithm in the LHCb Upgrade trigger

- This algorithm is being ported to the Upgrade, but the large amount of Velo-UT tracks might be a limiting factor.

- At Santiago we are contributing in both optimizing the algorithm and studying the possibility of using GPUs.

- This means to do all the decoding/clustering sequences (VELO, UT, Muon) purely on GPUs, integrating it with Gaudi, base of the LHCb computing framework.

- The idea is to use this algorithm as early as possible in the data-taking sequence.

- A similar algorithm might be defined using only VELO tracks, if limited by timing, but momentum estimate is much worse.

- This algorithm will be very useful not only to study strange decays, but also searches for exotic particles, like dark photons.
Other ideas being studied

- Large number of $K_S^0$ decay outside the VELO.
- Might be able to reconstruct the efficiently using Downstream tracks (no VELO information).
- Designing algorithms also for electrons. Might improve the efficiency for $R_K$, $R_{K^*0}$ or dark photon searches!
The use of GPUs for computation is being extended in science.

At Santiago we started to work with PyCUDA, for fitting and doing log \( \mathcal{L} \) scans, together with MultiNest, on a software called Ipanema-\( \beta \).

Big improvements in terms of timing and performance, being used in many analyses (CLs, angular analysis, ...).
Conclusions

• Tracking at 30 MHz is becoming a hard task at LHCb.

• Considering many options: changes in algorithms, inclusion of FPGAs, GPUs, ...

• Many ideas currently in Santiago to improve LHCb reconstruction, profiting from an upgraded detector and 7 years of experience on data-taking.

• Big interest on fast reconstruction algorithms, like VeloUT-Muon matching, to be used at the trigger level.

• Starting to work on GPU for the HLT1, defining framework, resources, benchmarks...