Optimization of the LHCb track reconstruction

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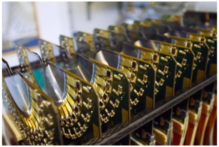
On behalf of the LHCb Collaboration

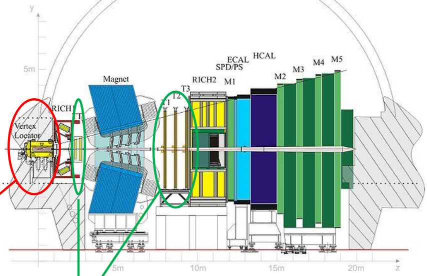
The LHCb tracking detectors

- LHCb is a dedicated heavy flavour physics experiment at the LHC
- Its primary goal is to look for indirect evidence of new physics in CP violation and rare decays

Requirements:

- Close to the beam
- Vertex and Tracking capabilities
- Particle identification





Vertex Locator: silicon strip detector

- Two moving halves
  - Openable during injection phase
  - Few mm from the beam line during data taking
- Excellent vertex resolution: 13 μm in x/y and 71μm in z for a PV with 25 tracks

Tracking system: silicon+straw tube technologies

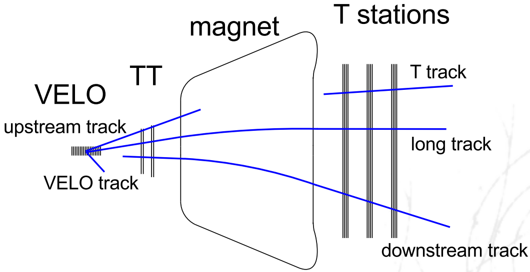
- Excellent mass resolution: ~24MeV/c^2 for 2-body B decays
- Tracking efficiency >96% for long tracks from B (from data, with tag-and-probe method)

[LHCb detector performance]

[Measurement of the track reconstruction efficiency at LHCb]

Tracking definition: track types

- **Long tracks**: Traverse full tracking system.
- **VELO tracks**: Have hits in both the r- and ϕ-sensors but are not matched to hits in other sub-detectors.
- **Upstream tracks**: Low momentum particles that are bent out of acceptance by the magnetic field.
- **T tracks**: Only reconstructed in the T stations, can originate from very long lived particles or material interactions.
- **Downstream tracks**: Made by charged daughters of long-lived particles with a vertex displaced from the interaction point (K_s^0,Λ).



Run I vs Run II

Conditions	Run I	Run II
$\sqrt{s}$	$7-8$ TeV	13 TeV
Bunch spacing	50 ns	25 ns
Output rate HLT1	80kHz	150kHz
Time budget HLT1	20ms/event	35ms/event
Time budget HLT2	150ms/event	350ms/event

- For the upgrade of LHCb we plan to have a full-software trigger

  [Upgrade TDR: LHCb trigger and online]

  - Run II proof of concept: can a complete physics analysis be done based on a DST produced in the HLT?
  - Needed to have the same reconstruction chain for offline and online: **strong requirement imposed on the reconstruction time and on the performance online (efficiency, ghost rate)**

Optimization for Run II

- Optimization needed to face the new conditions
  - Tuning of parameters
- Improving the reconstruction chain: excellent performance (efficiency, ghost rate) within the time budget
  - **HLT1:** critical the time (35ms per event)
  - **HLT2:** critical the performance (to be as offline)

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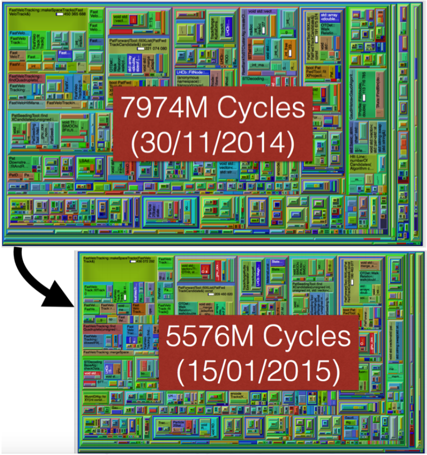
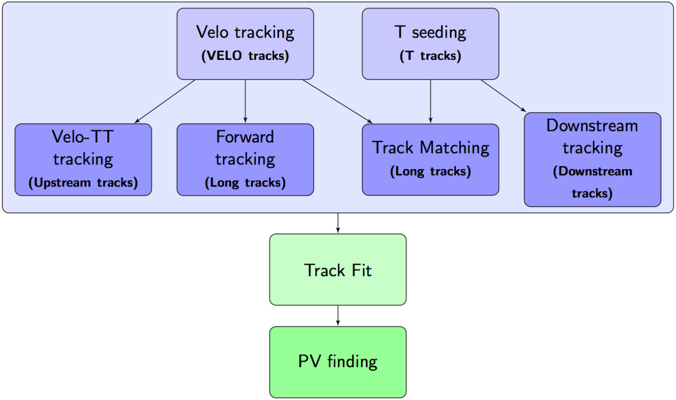
- Refactoring of the code
- Changes in the chain to speed it up / development of new algorithms

Code refactoring

- Many areas of the code are heavy on vector algebra
- Use faster implementations exploiting vector instructions
  - Possible to gain $\mathcal{O}(30\%)$ in several algorithms (e.g. Kalman fit)
- New algorithms (i.e. clusterization) allowed to:
  - improve the performance (better efficiency, lower ghost rate)
  - reduce execution time with a proper data organization



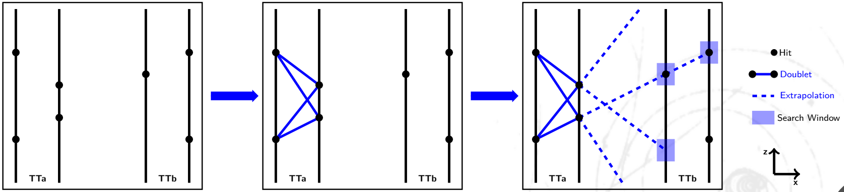
Tracking definition: algorithms



- Two algorithms to make long tracks (complementarity)
- Possibility to use VeloTT as input of the Forward tracking
- Track fit done with a Kalman filter procedure

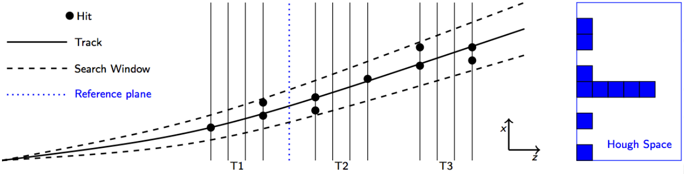
The VeloTT algorithm

- Linearly extrapolate VELO track to TT
- Select hits within a search window around the extrapolated track
- Form doublets of hits in the first two layers
- Extrapolate doublets to third/fourth layers and search for compatible hits
- If no four hit candidates found, repeat in starting from last two layers
- Fit each track candidate with a χ^2 fit and estimate q/p $(\delta p/p \sim 15\%)$
- Choose best candidate track based on # layers fired and χ^2
- More than 97% efficiency for tracks with $p_T > 200$MeV that hit at least 3 layers
  - Not total coverage of the LHCb acceptance by the TT detector: needed to recover tracks not leaving enough hits in the TT detector.

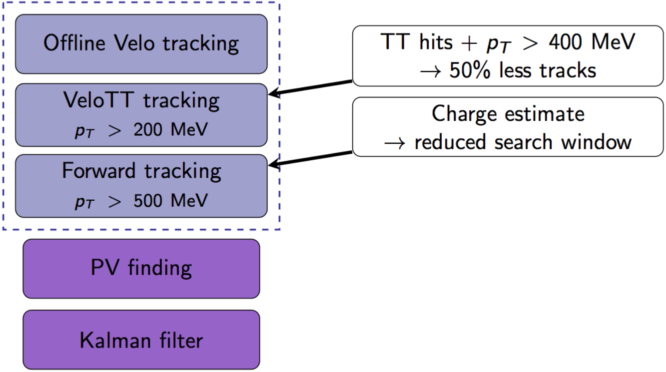


The Forward algorithm

- Linearly extrapolate VELO track to the T stations: **benefit if "only useful" velo tracks are passed**
- Open search windows in x each layer: **knowledge of the charge can be used to reduce it**
- Use VELO track state and knowledge of the $\vec{B}$ field to project each selected hit to the z position of the reference plane
- Hits from same particle expected to be projected to same x position, while random hits uniformly distributed $\rightarrow$ Hough transform
- Fit resulting clusters and remove outliers using χ^2 criterium
- Use a cluster search to add stereo hits
- Refit, remove outliers, select best track based on χ^2/dof



Effect of the VeloTT in the HLT1 chain



- 3 times faster reconstruction chain → HLT1 runnable in ~32ms with looser requirements than in run I
  - 500MeV p_T tracks available already at HLT1 level!
- 4 times less ghost rate, i.e. 6%
- 87% single track efficiency for $p > 3$GeV, $p_T > 500$MeV

HLT2 and offline reconstruction sequence

- Start from HLT1 tracks
- Second iteration of the Forward tracking
  - use only unused velo tracks (and un-used hits)
  - $p > 0.5$ GeV, $p_T > 80$ MeV
- Run the other tracking algorithms (Seeding, Downstream, Matching) on all the hits
- Efficiency for single long track from B of $> 90\%$ with 12% ghost rate.
- Only $1/4$ of the total budget spent for tracking: huge amount of time available for other procedures

Possible to reproduce offline efficiency and ghost rate staying in the time budget of 350 ms

Conclusions

- Several studies done to improve the performance of the reconstruction chain to face the new challenging condition of Run II
- Refactoring of the code allowed a speed up of $\mathcal{O}(30\%)$ in several algorithms
- Introduction of a new algorithm in the reconstruction chain for HLT1 allowed to fulfill the time budget allocated for Run II with even with looser requirements on the tracks

Possible to reproduce offline efficiency and ghost rate online

- Several studies ongoing to improve further for the upgrade conditions (e.g. investigate GPU-driven track reconstruction)