Trigger and Tracking for the LHCb Upgrade

Joint ETH-PSI-UZH PhD seminar, Zürich

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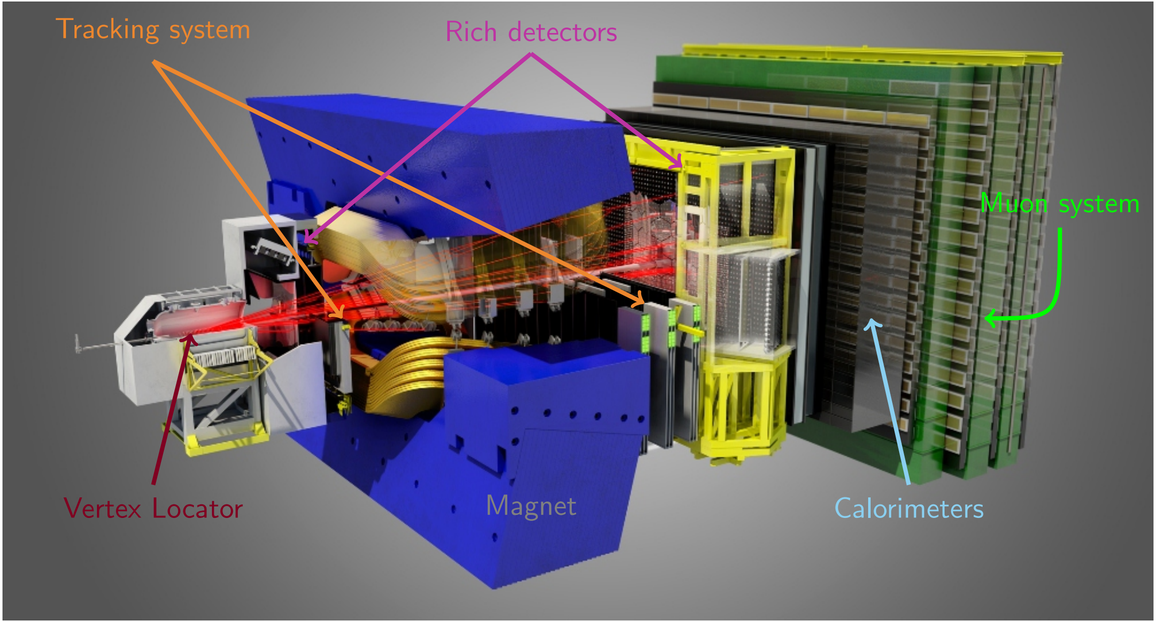
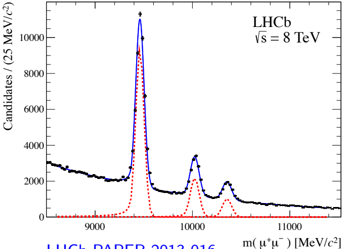

Tracking system
Rich detectors
Muon system
Vertex Locator
Magnet
Calorimeters

The LHCb experiment

- LHCb is a dedicated heavy flavour physics experiment at the LHC
- Forward spectrometer exploiting the large production of $b\bar{b}$ pairs in the $2<\eta<5$ region
- Its primary goal is to search for indirect evidence of New Physics in CP violation and rare decays of beauty and charm hadrons
- This requires:
  1. Excellent tracking (momentum resolution ($\Delta p/p = 0.4\%$ - 0.6%), IP resolution ($20\ \mu m$))
  2. Excellent decay time resolution (45 fs)
  3. Excellent particle identification ($K/\pi/p$ separation)
  4. Flexible, robust and efficient triggering (including on hadrons)



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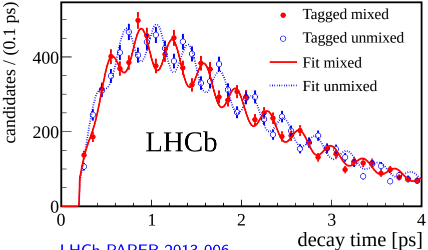

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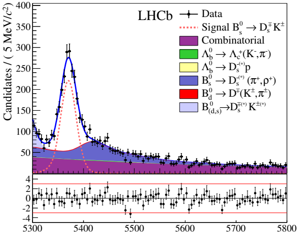
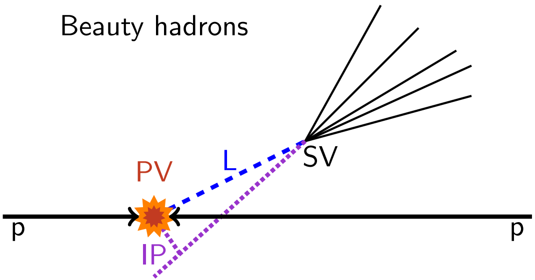
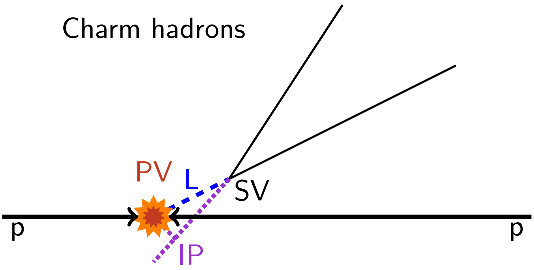


LHCb-PAPER-2014-038 $m(D_s^{\mp}K^{\pm})$ [MeV/c^2]



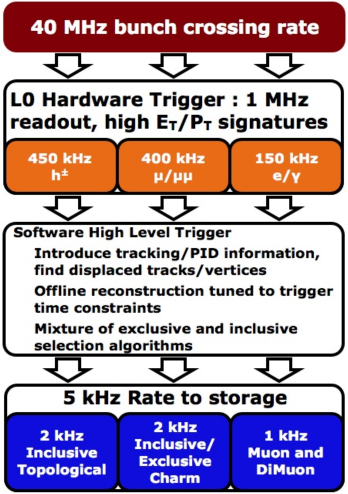


Beauty signatures

- $B^{\pm}$ mass 5.28 GeV, daughter p_T $\mathcal{O}$(1 GeV)
- τ ~1.6 ps ➜ L ~ 1 cm ➜ large IP

Charm signatures

- D^0 mass 1.86 GeV, large daughter p_T
- τ ~0.4 ps ➜ L ~ 0.4 cm ➜ smaller IP



LHCb trigger scheme: 2011-2012

Level 0 (L0) - Implemented in hardware

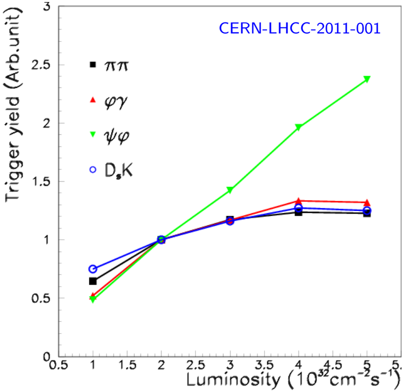
- High p_T and E_T signatures in muon and calorimeter systems
- **1 MHz detector readout**

Higher Level Trigger (HLT) - Flexible software triggers

- Track reconstruction and PV finding performed
- Combination of inclusive and exclusive selections

Motivation for Upgrade

- The experiment is performing well, operating in 2012 at $\mathcal{L} = 4 \times 10^{32}$ cm^{-2}s^{-1} (twice design luminosity) corresponding to ~ 2 fb^{-1} per year
- Going to higher luminosity is inhibited by 1 MHz detector readout
  ➜ Saturation of trigger yield for hadronic channels



Upgrade strategy

- Read out whole detector at 40 MHz
- Move to a full software trigger

LHCb Upgrade and the LHC

- Target luminosity is $\mathcal{L} = 2 \times 10^{33}$ cm^{-2}s^{-1}
- Key requirement is 25 ns bunch spacing
- Increase readout rate from 1 MHz to 40 MHz
- Sub-detectors must be replaced to be able to operate at a luminosities up to $\mathcal{L} = 2 \times 10^{33}$ cm^{-2}s^{-1}
- Upgraded experiment is expected to collect 50 fb^{-1} over 10 years

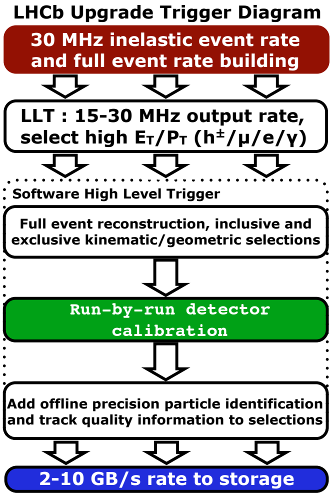
Physics motivations

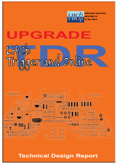
- Measurable deviations from the Standard Model are still expected but should be small
- The aim is to go to very high precision measurements for the most clean observables
- Expected statistical sensitivities become comparable to theoretical uncertainties
- Enhanced trigger flexibility allows expansion of LHCb physics programme

LHCb trigger scheme: Upgrade

- Main objective of Upgrade trigger is to remove 1 MHz bottleneck by implementing a trigger-less readout system
- Allows full inelastic collision rate of 30 MHz to be processed by a full software trigger
- Low Level Trigger with scalable readout rate (can act as "handbrake")
- Full event reconstruction followed by inclusive and exclusive selections
  - Offline like PID information available
- The estimated per-event timing budget is **13 ms**, which is very tight

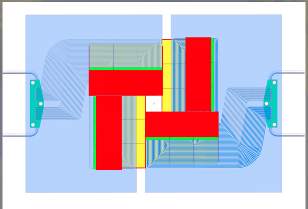
➜ Tracking algorithms must run as fast as possible!

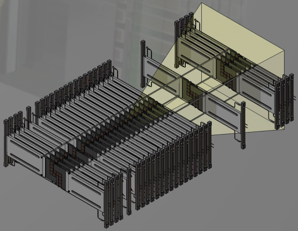


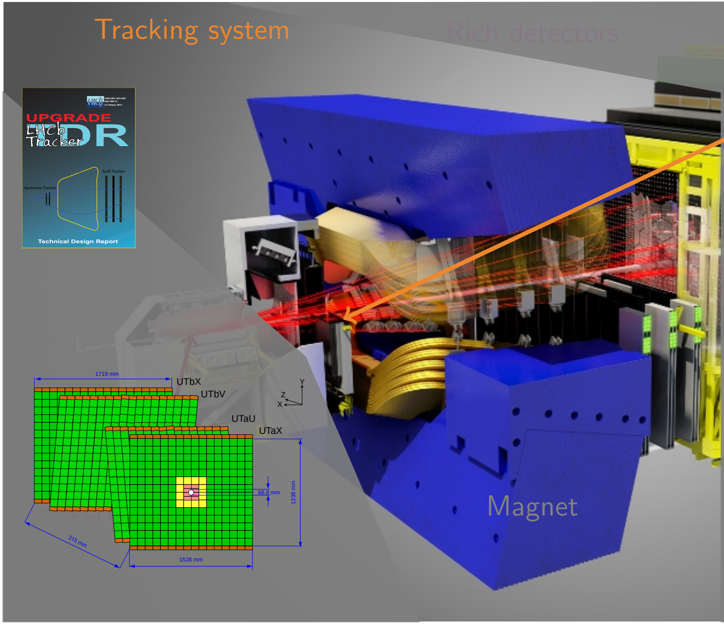


Vertex Locator (VELO)

- Silicon micro-strip ➜ pixel sensors
- 41 million 55 x 55 μm pixel sensors with micro channel CO_2 cooling
- First pixel only 5.1 mm from beam (was 8.2 mm)



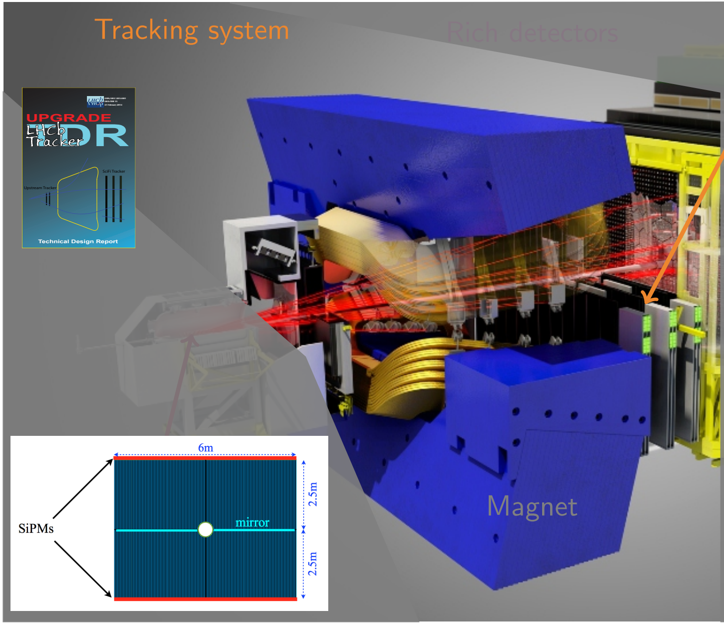




Upstream Tracker (UT)

- Four high granularity silicon micro-strip planes (X,U,V,X)
- Improved coverage of LHCb acceptance w.r.t current TT sub-detector
  - Circular hole of radius 33.4 mm at centre
  - ➜ Will play a larger role in track reconstruction in the trigger

Tracking system

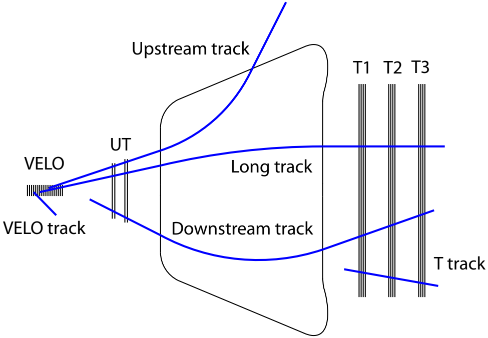


Scintillating fibre tracker (SciFi)

- Silicon micro-strips + straw tubes ➜ scintillating fibers
- Three stations (X-U-V-X)
- 2.5 m long multilayer ribbons of 250 μm diameter scintillating fibre with silicon photomultiplier readout
- Single fast detector covering 350 m^2

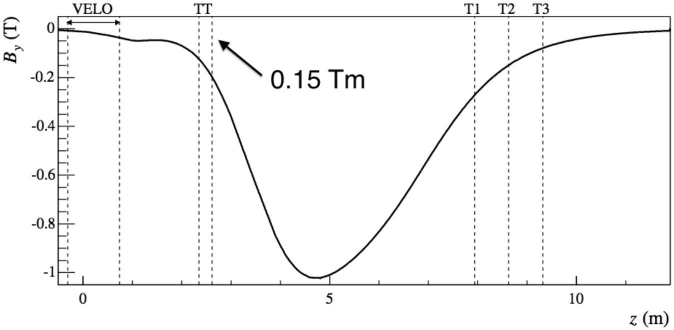
Track reconstruction

- The standard track reconstruction sequence for long tracks (Forward tracking) uses VELO tracks and adds hits from the SciFi sub-detector
- As there is no $\vec{B}$ field in the VELO, the momentum of the VELO track is unknown
- Large, symmetric search windows are required to find matching SciFi hits
- Due to large combinatorics, this approach is too slow meet trigger demands



Upstream tracking

- Upstream tracking takes VELO tracks and adds UT hits to form upstream tracks
- The fringe field from the LHCb magnet between the VELO and UT sub-detectors ($\sim$ 0.15 Tm) makes a momentum estimate possible ($\delta p/p \sim 15\%$)
- Previously only used to find low momentum tracks that were bent out of acceptance by the magnetic field
  - Not used in the trigger

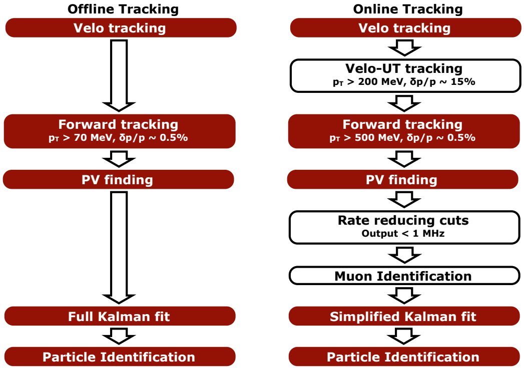


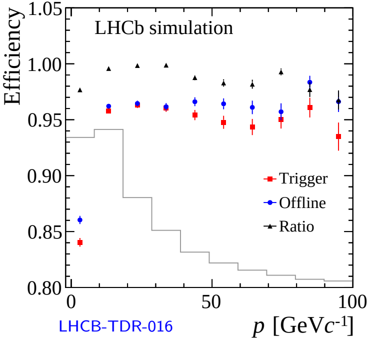
Idea

- Use upstream tracks as seeds to form long tracks
- Benefit from added momentum information
- Rewrite algorithm optimising for maximal efficiency for high p_T tracks while keeping execution time minimal

Result

- Using upstream tracks instead of VELO tracks
  - ➜ Charge and momentum of track segment
  - ➜ Can preselect on p_T
  - ➜ Smarter, smaller search windows
  - ✪ Greatly reduced execution time and ghost rate!
- Upstream tracking has become part of the baseline tracking sequence for the LHCb Upgrade trigger





LHCB-TDR-016

Track reconstruction efficiency

- Relative efficiency of the track reconstruction in the Upgrade trigger w.r.t to offline tracking sequence is 98.7% for tracks with $p_T > 500$ MeV/c
- Large reduction in the ghost rate

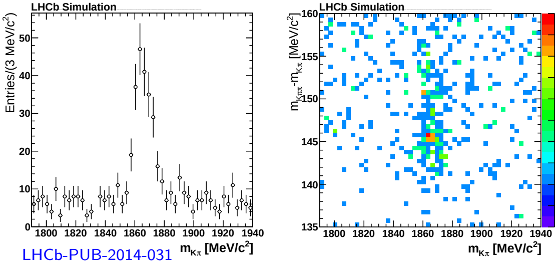
Execution time

- Estimated per-event timing budget: 13 ms
- **Execution time reduce by factor 3**
- Can reconstruct tracks with $p_T > 500$ MeV/c consuming only 40% of available CPU resources
- Time available to perform full RICH PID

Algorithm	CPU time [ms]
VELO tracking	2.0
VeloUT tracking	1.3
Forward tracking	1.9
PV finding	0.38
Total	5.6

Lifetime unbiased hadronic triggering

- An all-software trigger offers almost unlimited flexibility in designing trigger selections
- Able to select on particle lifetime, not proxy variables
  - ➜ No bias on the shape of the decay time distribution
    - ➜ Reduced systematic uncertainties
- First time for hadronic final states at a hadron collider!



LHCb-PUB-2014-031

Events selected by the lifetime-unbiased $D^0 \to K\pi$ Cabibbo-favoured trigger selection corresponding to 30 ms of data-taking in the upgrade.

Summary

- LHCb will upgrade its tracking system in 2018-2019 in order to:
  - Cope with the new running conditions
  - Fullfil ambitious new physics plans
- Changes in technology are necessary in many of the sub-detectors
- The Upgrade tracking system will allow LHCb to be the first hadron collider experiment to operate a software-only trigger at the full event rate!
  - ➜ Ability to do physics with the output of the trigger
  - ➜ Allows lifetime unbiased hadronic triggers
- The use of upstream tracks in the track reconstruction makes it possible to reconstruct all tracks with $p_T > 500$ MeV/c using only 40% of the available CPU resources
  - Time available to perform full RICH PID

VeloUT tracking algorithm

- Linearly extrapolate VELO track to UT
- 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
- Choose best candidate track based on # layers fired and χ^2