LHCb's Forward Tracking Algorithm

Run 3 CPU-based Online Track Reconstruction

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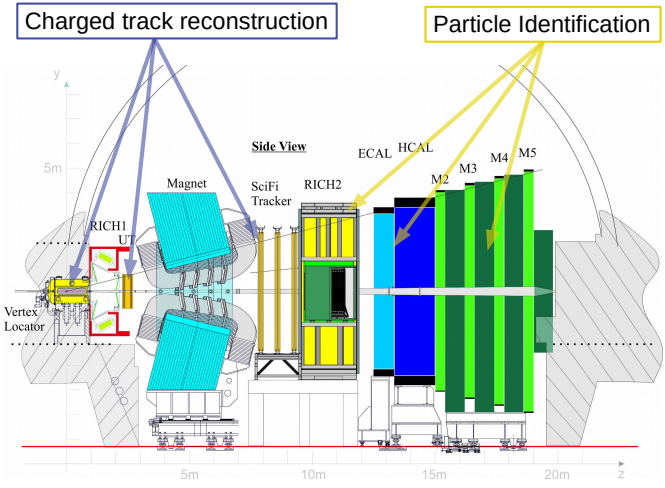
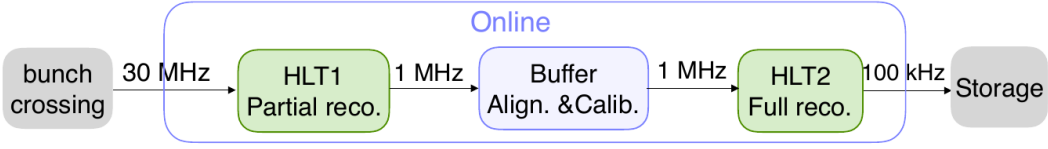
on behalf of the LHCb collaboration

7th Connecting The Dots Workshop 1st June 2022

Run 3 LHCb Detector



LHCb's Software Trigger for Run 3



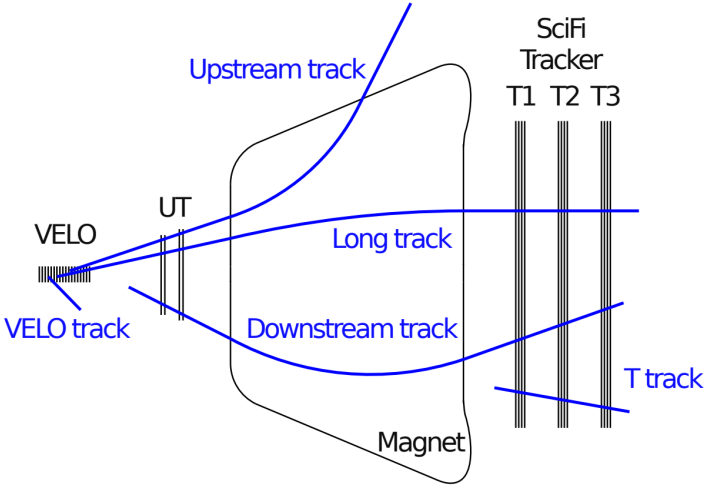
LHCb's Software Trigger for Run 3

- "Allen: A high level trigger on GPUs for LHCb" Comput Softw Big Sci
- Tom's talk yesterday and CTD2020
- Alessandro's talk tomorrow

LHCb's Software Trigger for Run 3

- full offline-quality event reconstruction on CPUs
  - track reconstruction → this talk
  - track parameter estimation using Kalman Filter
  - particle identification
  - neutrals reconstruction
  - candidate selection
- see also Sevda's talk later today
- for alignment see Florian's talk tomorrow

HLT2 Track Reconstruction - Track Types



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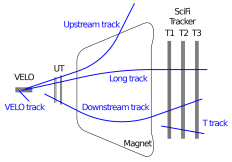
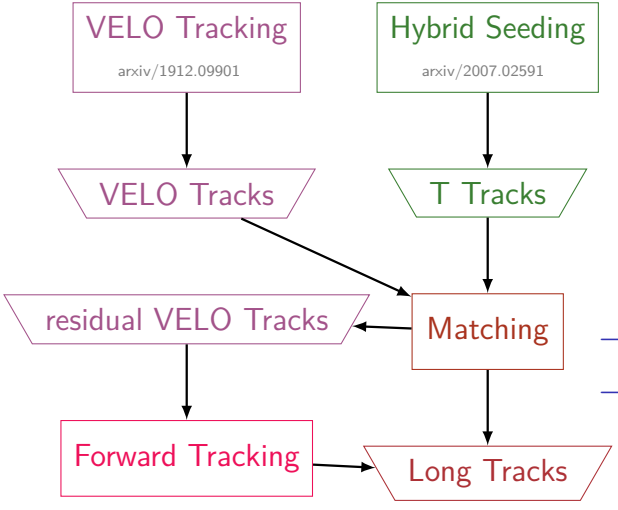
HLT2 Track Reconstruction Sequence



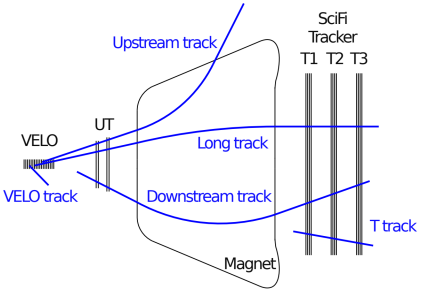


- two algorithms find Long Tracks
  1. Neural Network (MLP) Matching VELO to T Tracks
  2. Forward Tracking

→ avoid redundancy for speed

→ run Forward Tracking on not-matched VELO tracks

Forward Tracking - Intro



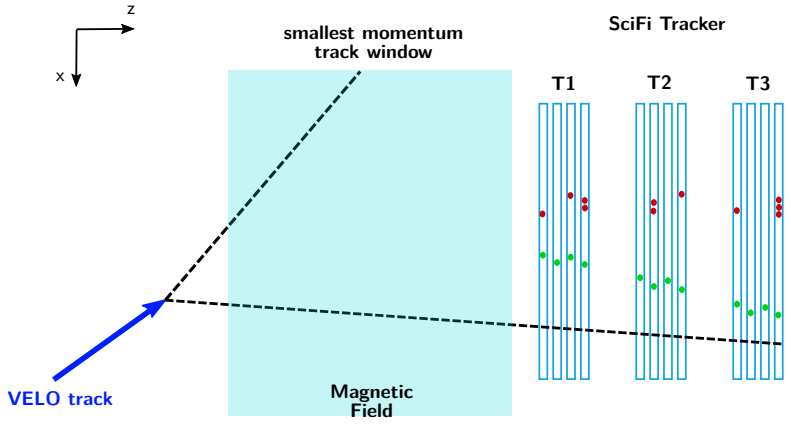
Goal: find "Forward" extension
to VELO track in SciFi Tracker
+ estimate momentum

- extension is set of 10-12 SciFi hits
- fringe magnetic field in SciFi Tracker → hits on slightly curved line

→ Hough-like transform algorithm to recognise lines

Forward Tracking - Algorithm

1. define hit search window for VELO track state $(x, y, \frac{\partial x}{\partial z}, \frac{\partial x}{\partial z}, \frac{q}{p})$
   $\frac{q}{p}$ unknown, assume $p > 1.5\,\text{GeV}$ use Polynomial$(\frac{\partial x}{\partial z}, \frac{\partial x}{\partial z}, p)$



Forward Tracking - Algorithm

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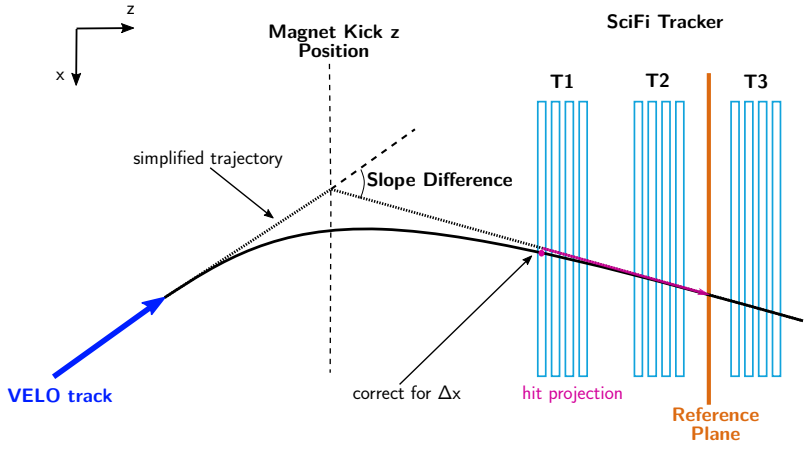
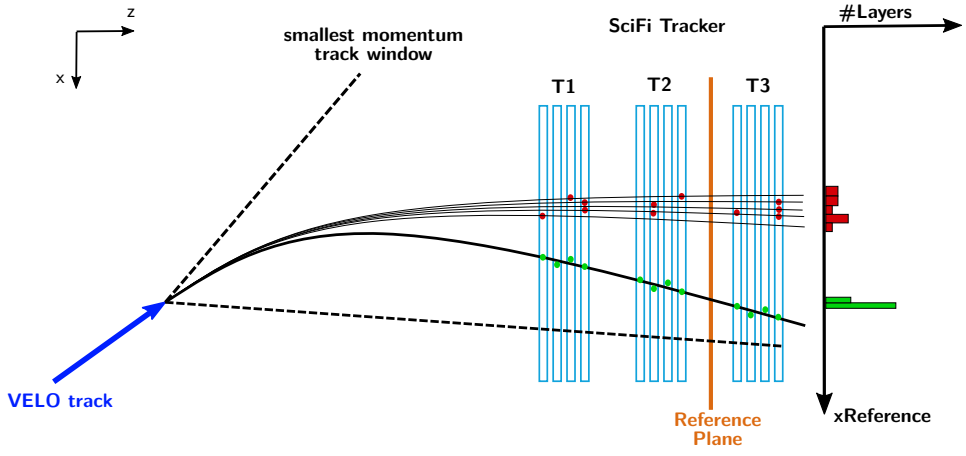
2. treat magnet as optical lens to simplify track and hit projection



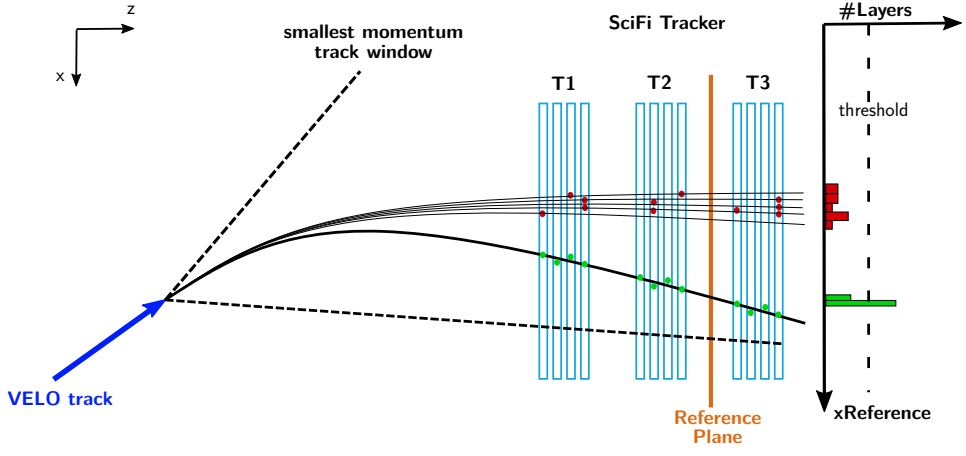
Forward Tracking - Algorithm

3. Hough-like transform: project all hits in window to reference plane and count number of SciFi layers in histogram



Forward Tracking - Algorithm

4. scan histogram, collect hits from bins above threshold



Forward Tracking - Algorithm Summary

1. define hit search window
2. treat magnet as optical lens to simplify track and hit projection
3. Hough-like transform: project all hits in window to reference plane and count number of SciFi layers in histogram
4. scan histogram, collect hits from bins above threshold

$\rightarrow$ found set of SciFi hits extending VELO track

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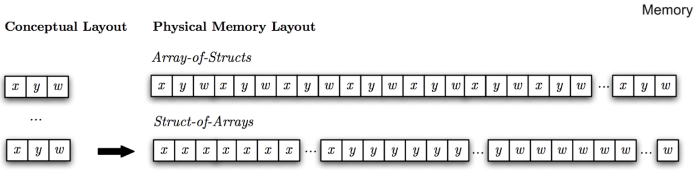
5. clean-up hit set and fit using 3rd order polynomial
6. estimate q/p from fit result

Forward Tracking - Event Throughput Optimisation

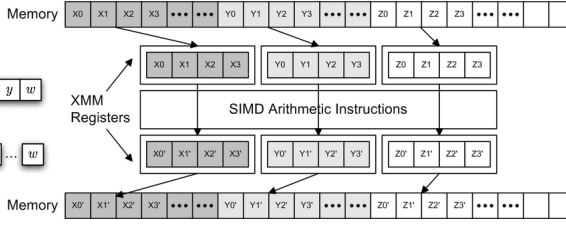
- typically trade-off between throughput, track reconstruction efficiency, fake track fraction

But: can improve throughput using modern CPU capabilities

→ Single Instruction Multiple Data (SIMD) with Structure-of-Arrays (SOA) data layout, "Vectorisation"



Arthur Hennequin. Performance optimization for the LHCb experiment



Ma, Wan-Chun, Yang, Chia-Lin. (2003) 10.1007/3-540-36228-2 134.

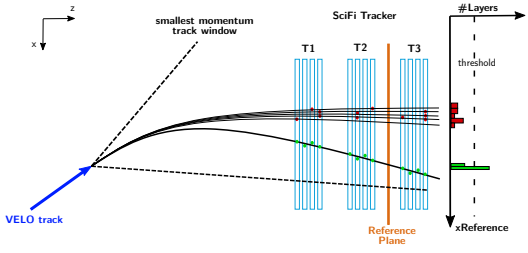
Forward Tracking - Vectorisation

- hits and #Layers stored in SOA layout → apply SIMD

→ project multiple hits

→ threshold scan multiple #Layers

- 8 single precision floats/integers in parallel (AVX2)

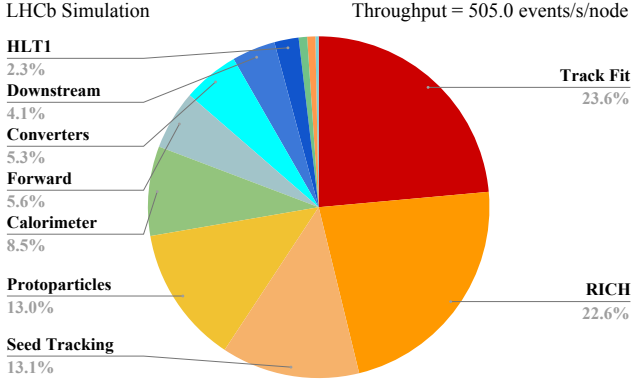


→ increases event throughput of Forward Tracking by 60%

HLT2 Reconstruction Sequence Throughput

LHCb-FIGURE-2022-005

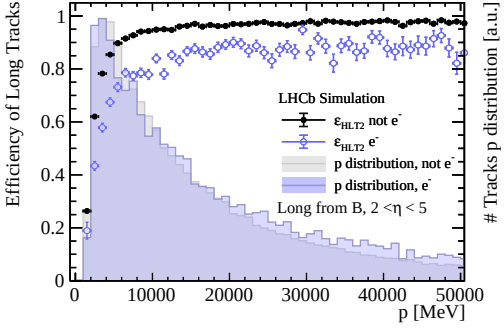
- throughput break down of track reconstruction and particle identification
- not including candidate selections

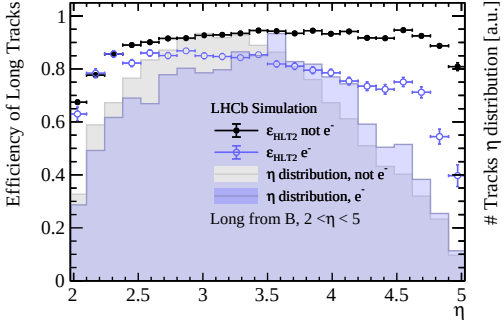


→ Forward Tracking not dominating component for throughput

Forward Tracking - Reconstruction Efficiency

- more than 90% efficiency for high momentum central tracks from B meson





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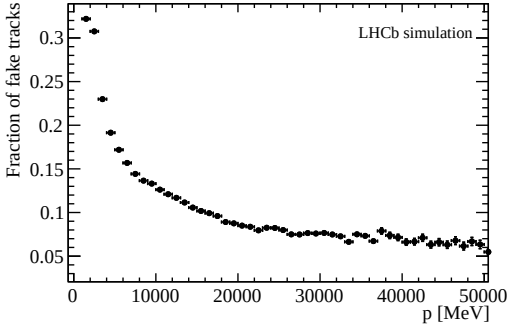
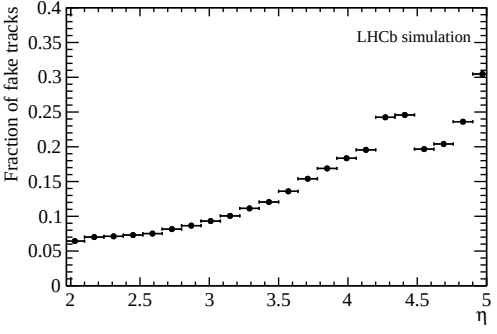
Forward Tracking - Fake Track Fraction

- high pseudorapidity region has high hit density

→ more combinatorics to form fake tracks





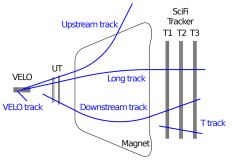
LHCb-FIGURE-2022-005

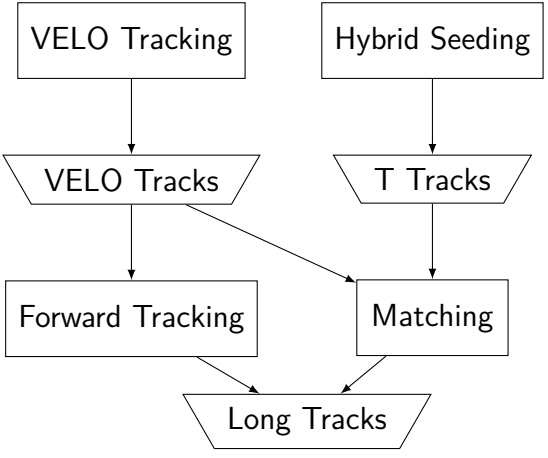
Summary

- Forward Tracking reconstructs Long Tracks in HLT2
- pattern recognition via Hough-like transform
- event throughput 60% increased by using CPU vectorisation
- reconstruction efficiency $> 90\%$ for high momentum tracks from B meson

Backup

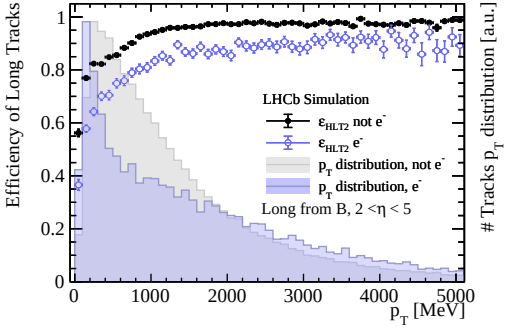
HLT2 Track Reconstruction Sequence

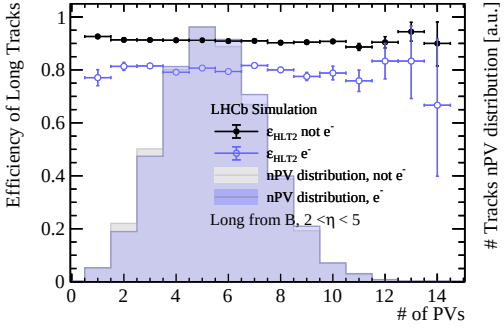




- legacy Run-2-like sequence
- redundancy in finding Long Tracks
- slow because too much work done + need to remove tracks found twice

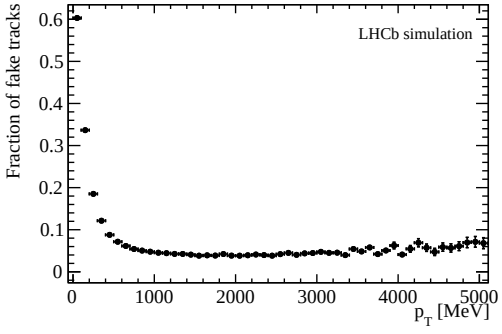
Forward Tracking - Reconstruction Efficiency

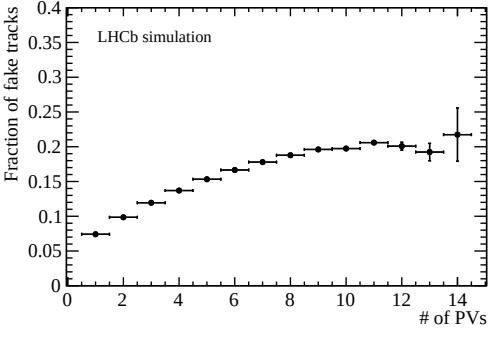




LHCb-FIGURE-2022-005

Forward Tracking - Fake Track Fraction





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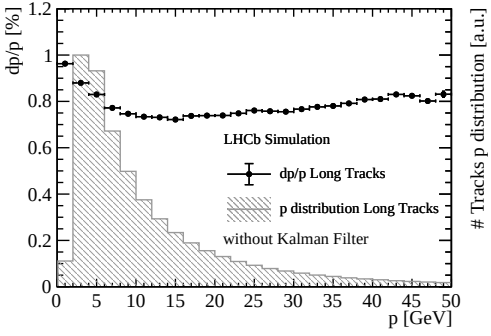
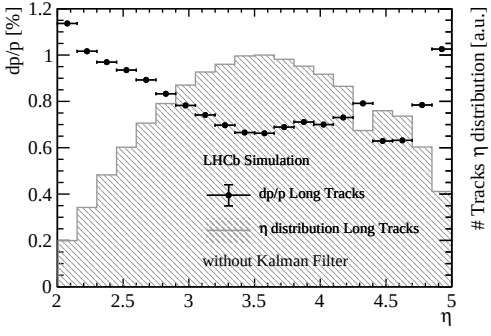
Forward Tracking - Momentum Resolution





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