Track finding at LHCb

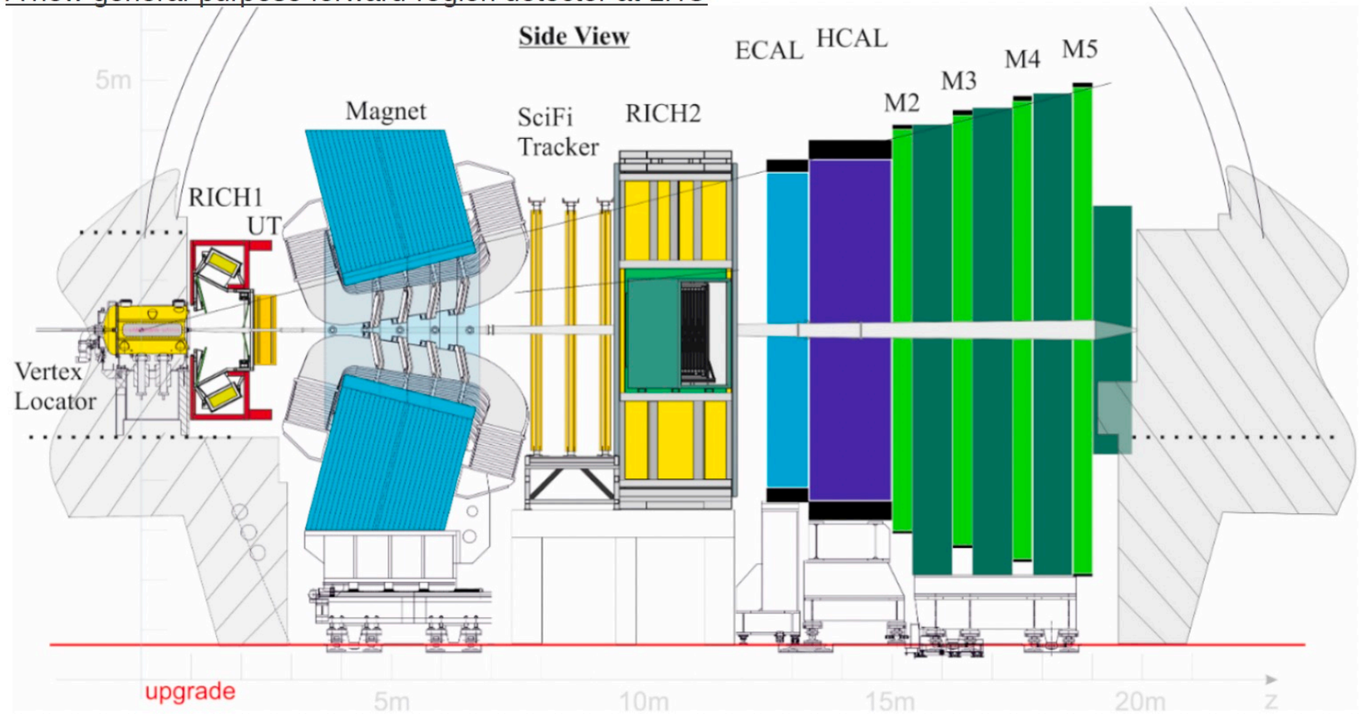
By: M. Waterlaat

Overview

- LHCb
- VELO
  - The problem
- Other strategies
- Search by triplet
  - Performance
  - Caveats
- Future challenges
- Summary

LHCb experiment in Run 3

- LHCb conditions in Run 3: luminosity of 2×10^{33} $cm^{-2}s^{-1}$, $\sqrt{s}$ = 13.6 TeV, visible collisions per bunch $\mu \sim 5$
- New tracker detectors, upgraded electronics, fully software trigger, ...
- A new general-purpose forward-region detector at LHC



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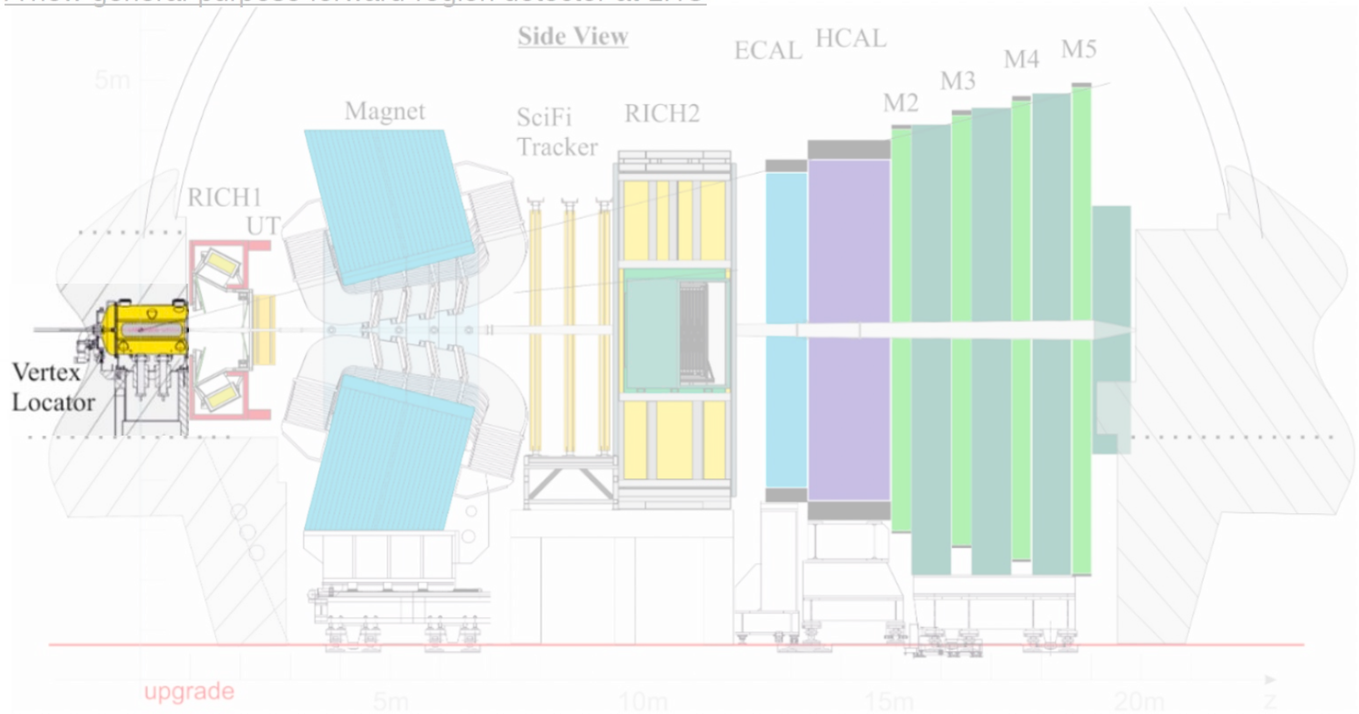
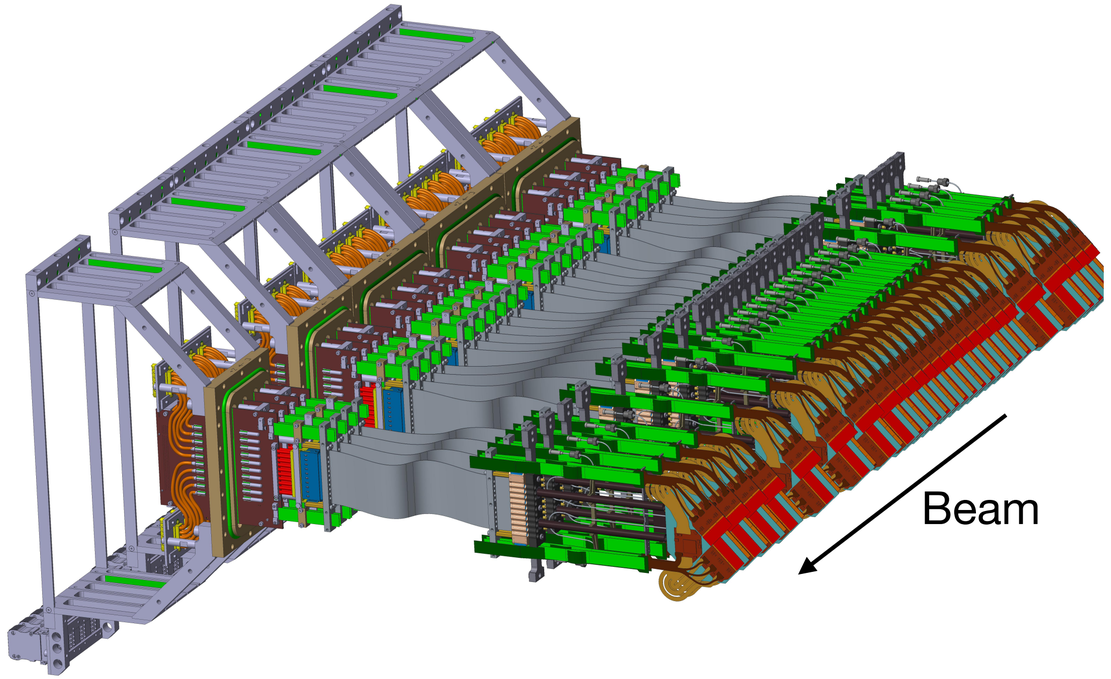


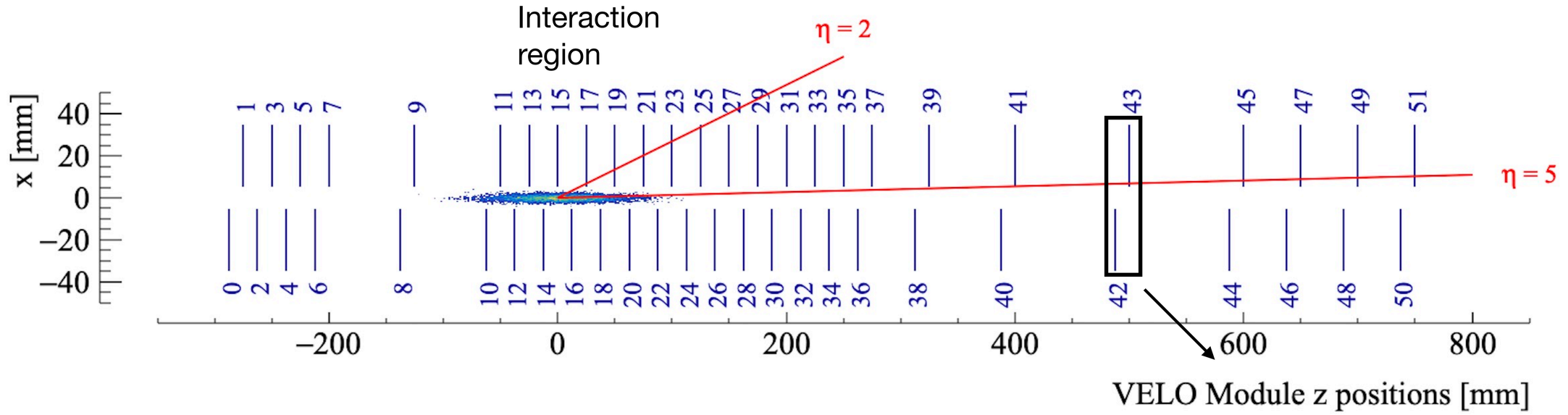
The VErtex LOcator (VELO)

The Upgrade 1 VELO

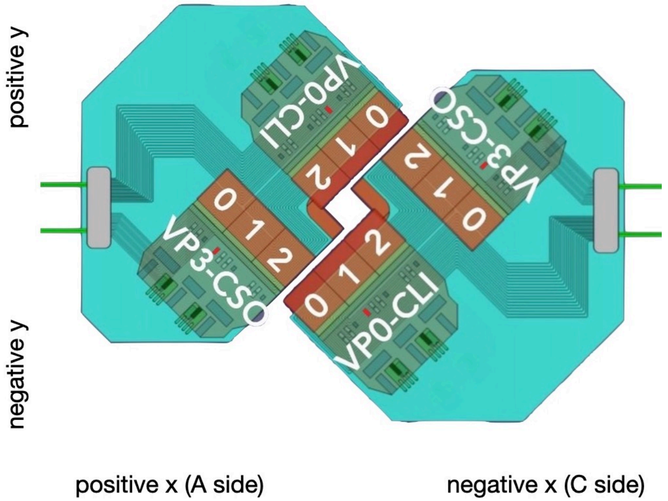
- The VErtex LOcator (VELO) is a silicon-pixel tracker with its closest pixels located 5.1 mm from the luminous region.
- 52 modules comprising 2 movable halves.
  - Halves live inside a secondary vacuum
- **Primary goals**
  - Track reconstruction and Vertex finding



Projected VELO

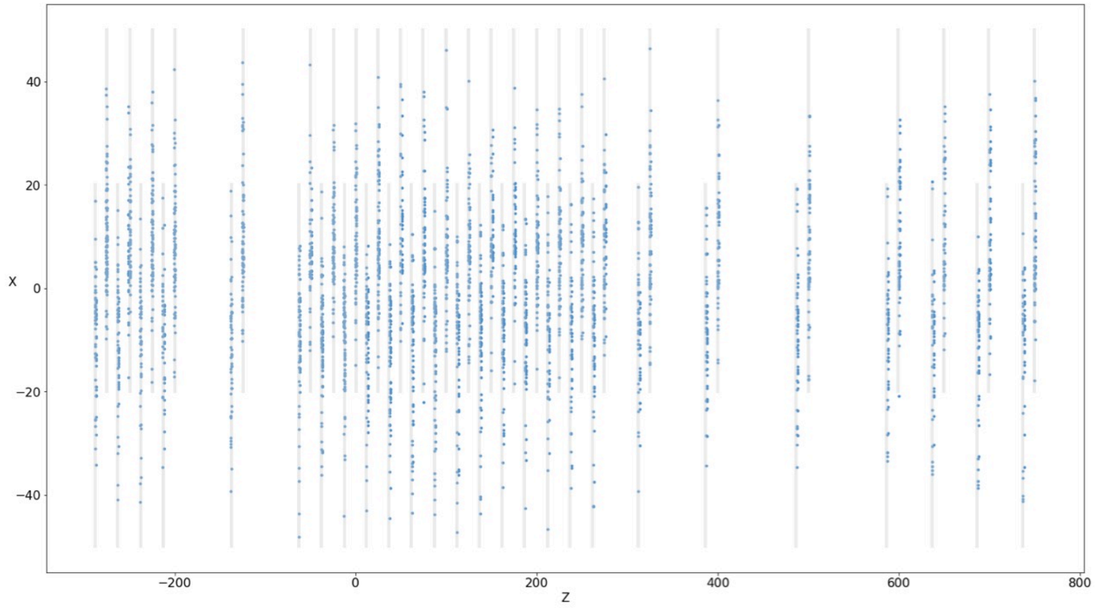


- LHCb's **physics acceptance** between $2 \leq \eta \leq 5$ (about $0.8^\circ \leq \theta \leq 15^\circ$)
  - Backwards stations needed for Primary Vertex (PV) reconstruction

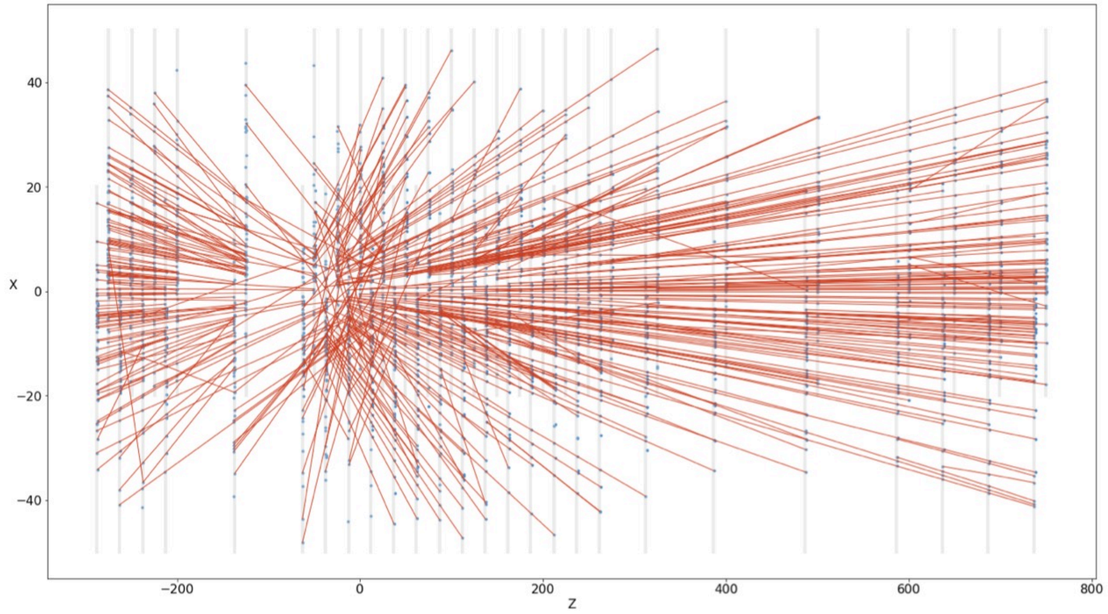


How does an event look in reality

Hits in the detector



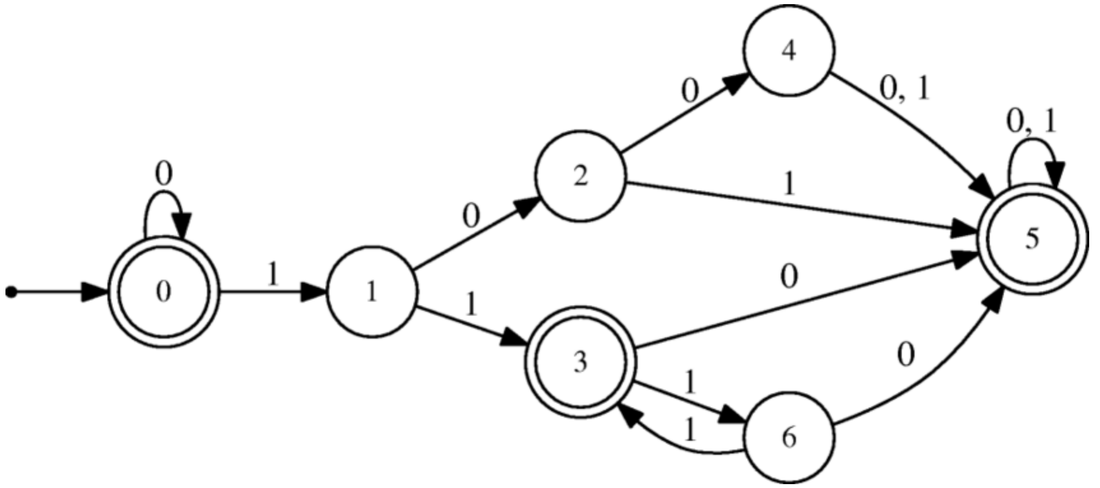
Reconstructed tracks



- **Tracking**: Reconstruct a particle's trajectory from hits in its path.
  - After a track has been found it is fitted with a Kalman-filter assuming a straight line (Not discussed in this talk)
  - Each event has O(5) interactions with each having O(100) tracks

Other studies

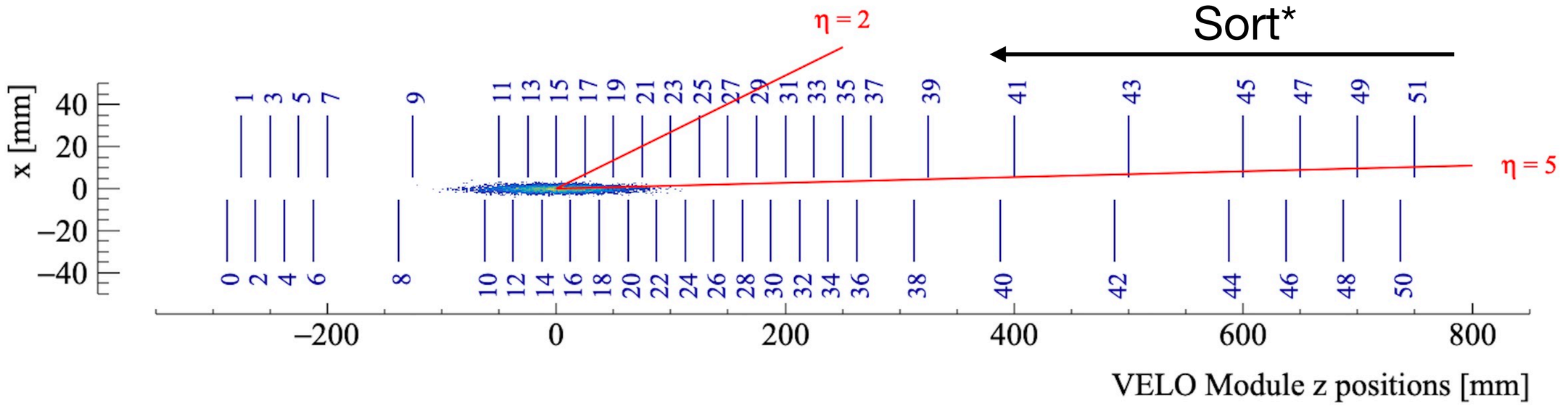
- Parallel studies looked into techniques like:
  - Hough Transform
    - See later talk
  - Clustering method
    - Project hits on origin, after apply a clustering algorithm
  - Automata method
    - Directed graph optimization



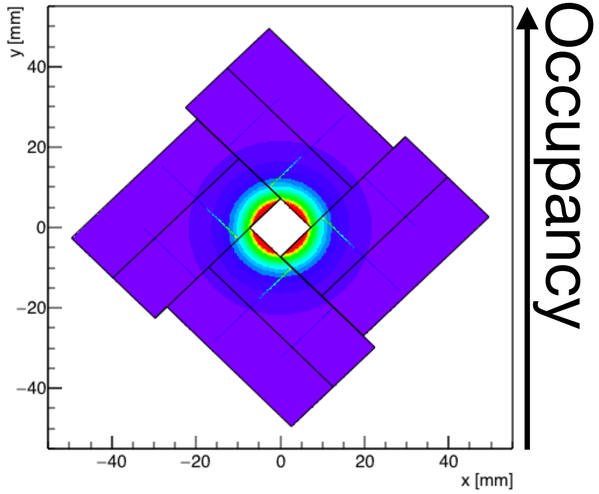
Links with more information can be found in [link]

Sorting

*Assuming forward tracks



- Hits are sorted
  - From least dense —> dense regions



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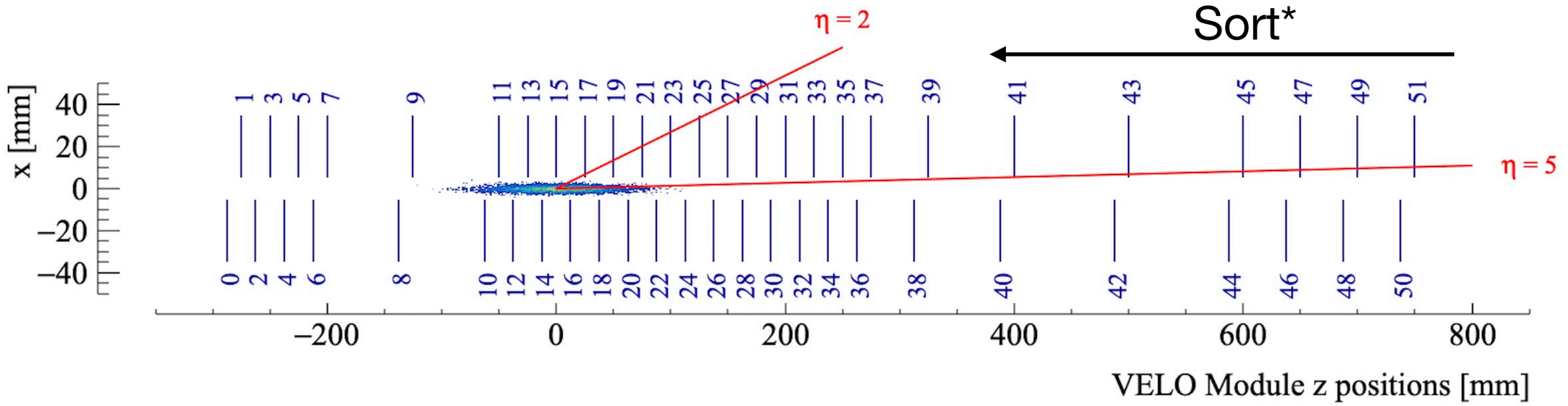
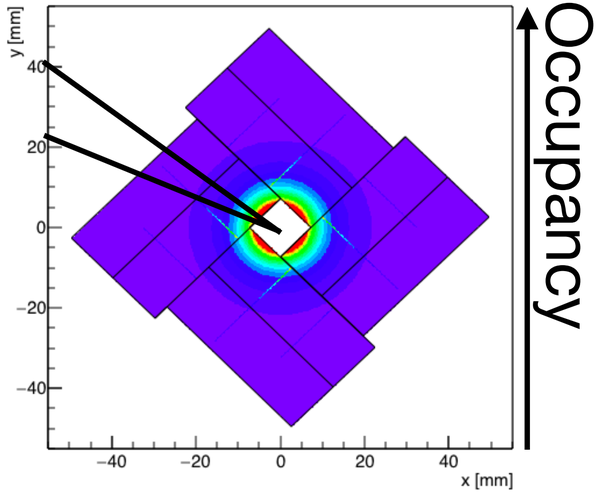
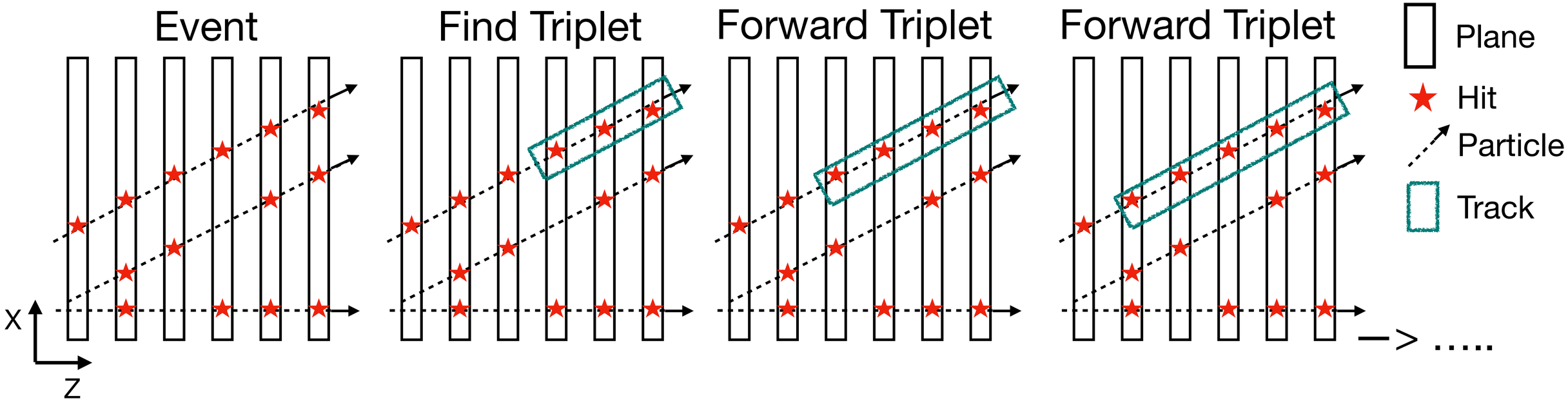


- Hits are sorted
  - From least dense —> dense regions
  - Bin in regions of ϕ

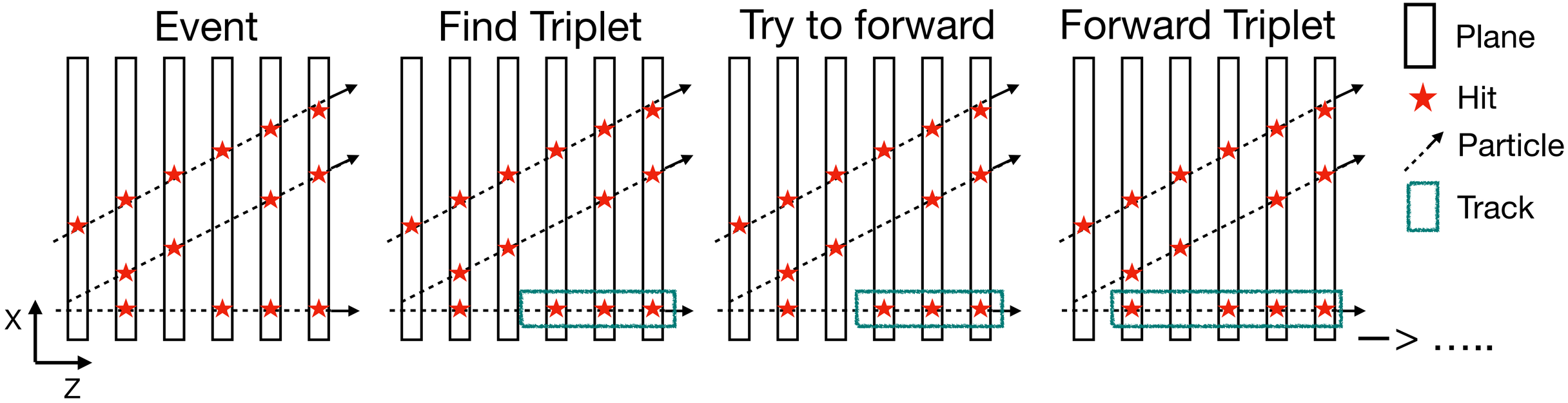


Search by triplet (I)



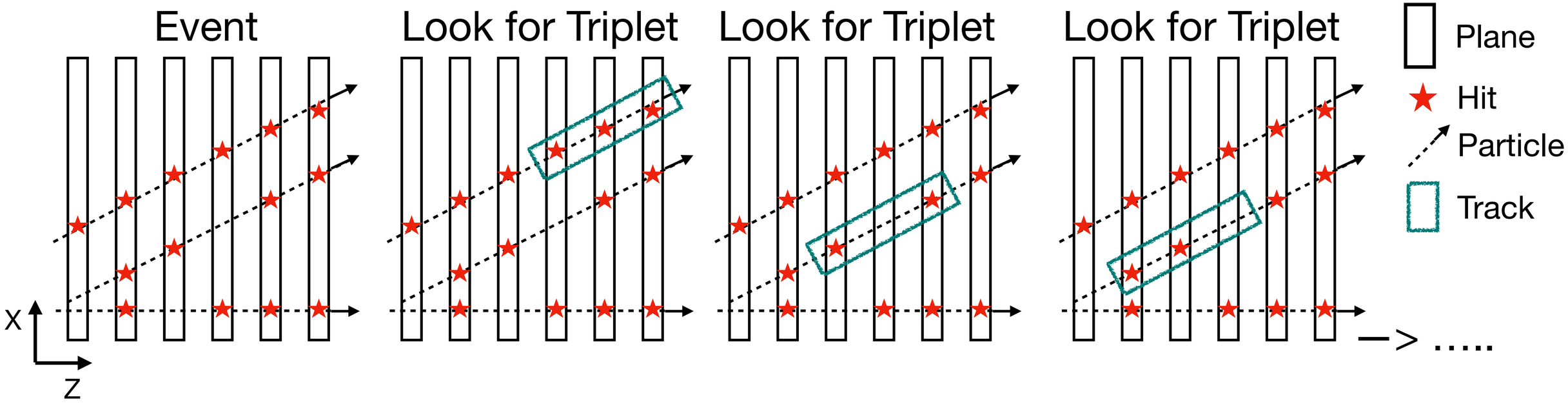
- Start by **finding a triplet**, also called Seed, defined as three consecutive hits
  - Forward the Seed by looking for hits in following layers
  - Continue until all possible planes are checked
- Constrained by, among others, max scattering in triplet as well as total track

Search by triplet (II)



- Start by finding a triplet as before
  - LHCb's default pattern recognition allows for missing layers in the forwarding
  - Allows for inefficiencies in detector without dominating the reconstruction performance

Search by triplet (III)

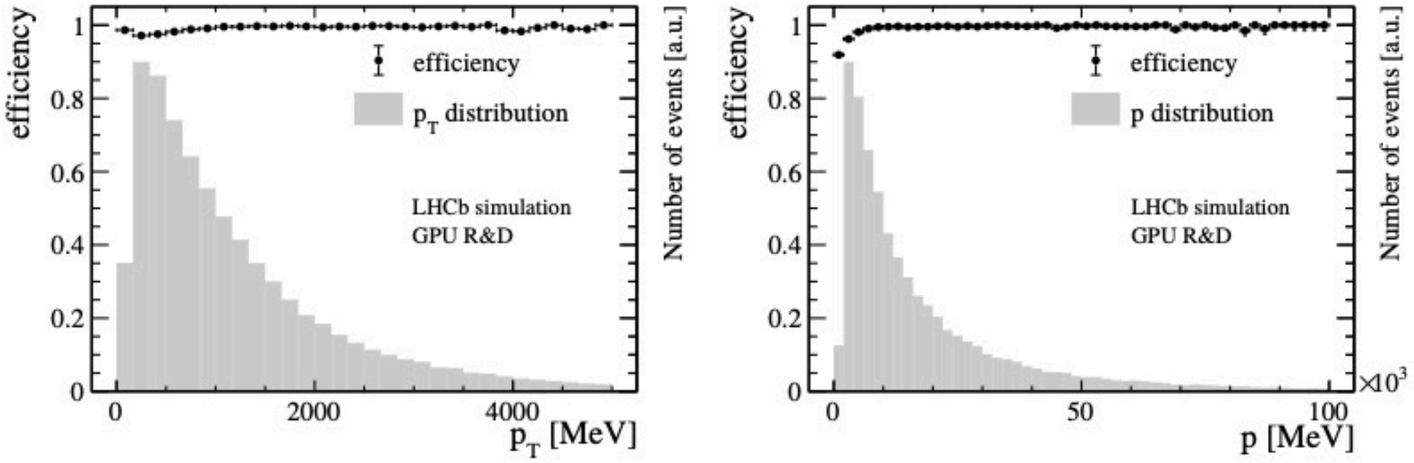


- If no triplet is found, the window is shifted forward iteratively
  - If no Seed is found, no track will be produced
    - More details later

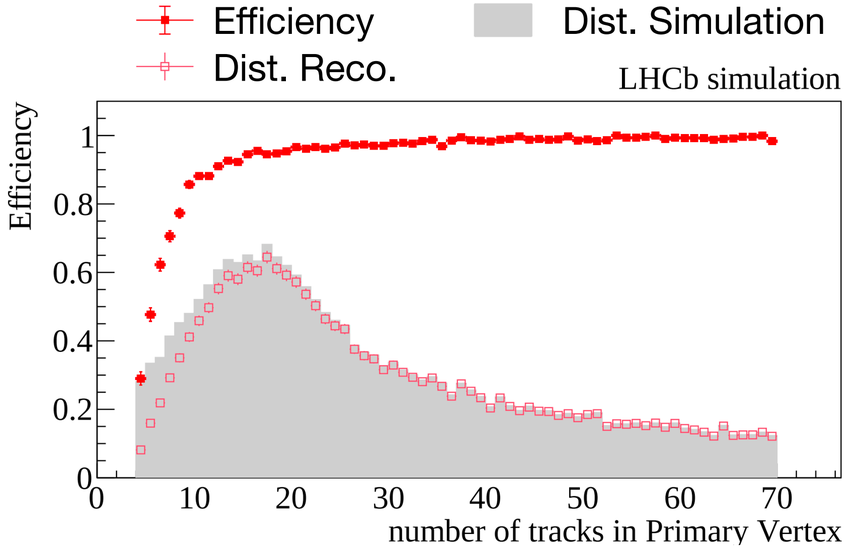
Performance in the current detector

*Specifics can be found in the links

[link]



[link]



- Reconstruction runs successfully in the trigger at 30MHz. on GPUs*
  - Reasonably flat over momenta spectra
  - Good performance in vertex finding
- Maximum tracking complexity calculated to O($m \cdot n^2 \cdot log(n)$) [link] for m planes and n hits per plane

Comparison to previous implementations

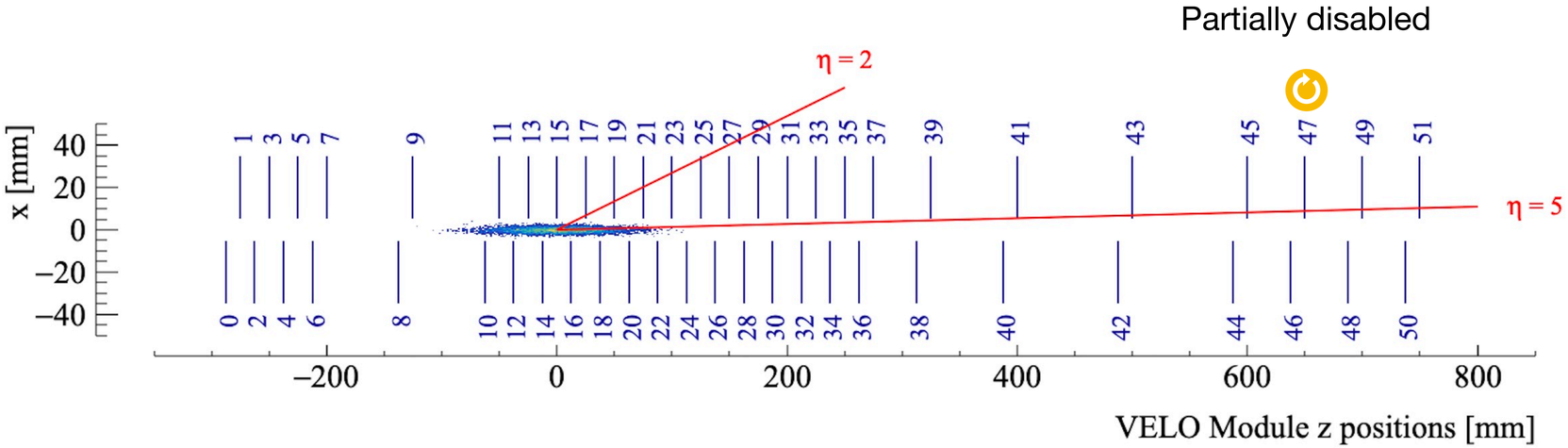
LHCb phys. tracks

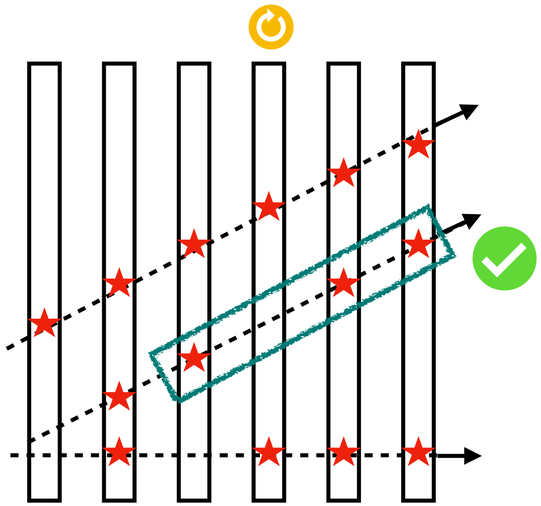
Particle category	Reference (09-07-2018)				Latest version (10-07-2020)			
	Reco. eff.	Clone fraction	Hit purity	Hit eff.	Reco. eff.	Clone fraction	Hit purity	Hit eff.
All	95.36	0.60	99.07	97.58	98.52	2.14	99.30	96.45
Strange	87.45	0.60	98.04	97.65	98.13	1.58	99.48	97.35
From B	96.88	0.51	98.96	97.85	99.30	1.16	99.74	98.11
Electrons	70.25	0.72	90.93	90.64	97.38	2.74	98.18	97.02
From B electrons	79.00	1.13	94.00	93.52	97.00	3.68	98.42	96.68
Overall fake fraction	3.25				0.86			

[link]

- Higher overall reconstruction efficiency
  - Slight increase in clone fraction (1 particle producing 2 tracks)
  - Comparable hit purity (Do all hits belong to the same particle) and hit efficiency (Did it find all hits belonging to the particle)
  - Fake track rate decreased significantly

Accounting for detector effects





|x|x|x|o|o|

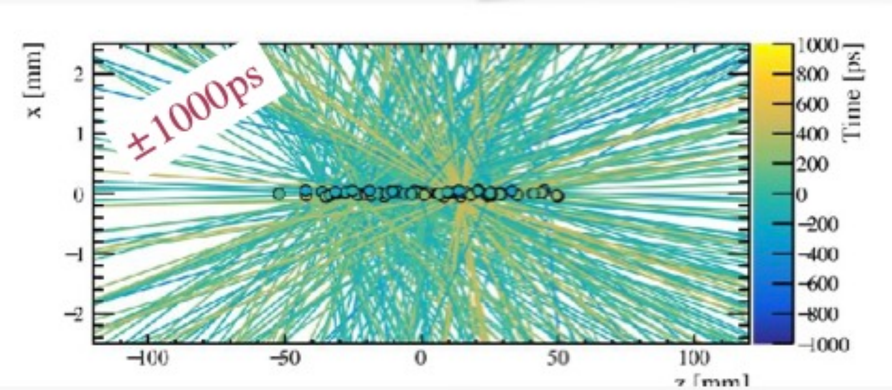
|x|x|o|x|o|

|x|o|x|x|o|

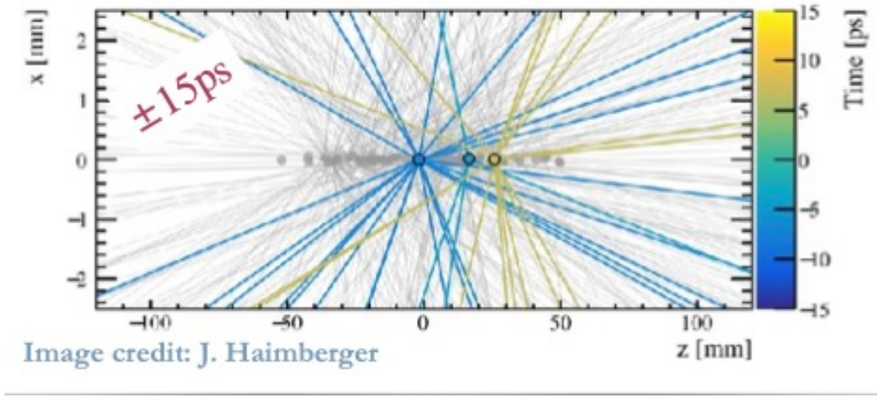
…

- Unfortunately our detector isn't perfect, but does this need to be a problem?
  - Increase the seeding window to look for 3 per N planes
  - Increase in complexity as well as fake track rates (impacts physics)
- Recently developed a method to allow for selective seeding windows per plane

Upgrade to the detector

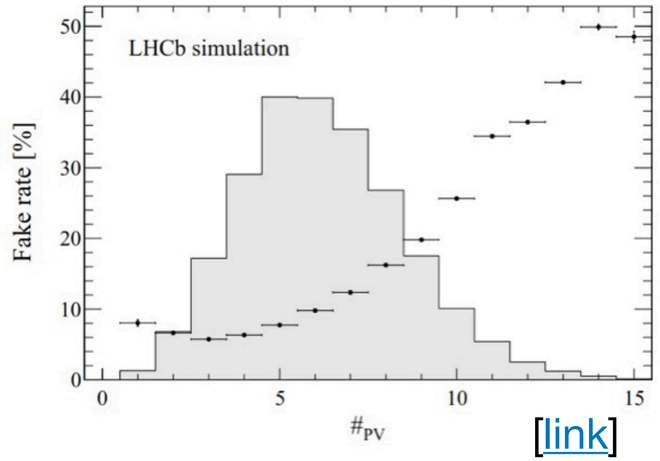


Timing



- Upgrade planned to start taking data around 2035
  - Increase in number of colliding protons on O(5)
    - Introduce timing to increase separation in the event
  - Tracking strategy not finalized for the moment
    - E.g. How to tackle fake track rate

These are current conditions



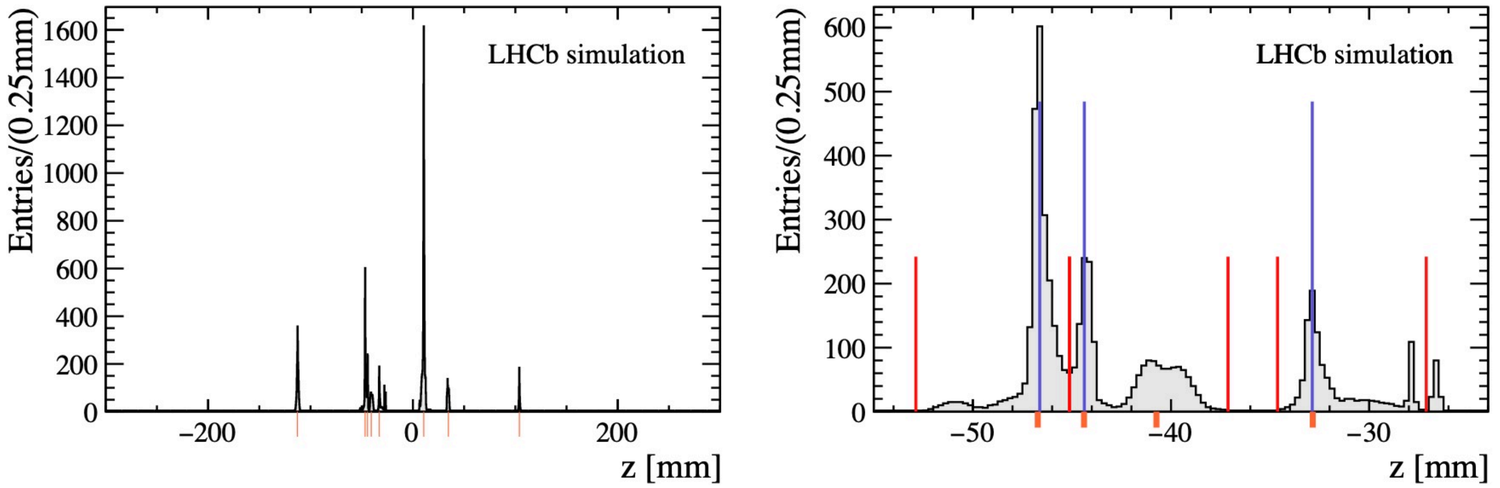
[link]

Summary

- Many strategies have been studied
- Pattern recognition by search by triplet implemented in our software trigger
  - Both on GPU and CPU
  - Improvements in reconstruction efficiency and robustness
- Algorithm is proven to be flexible to e.g. allow for detector effects

Backup

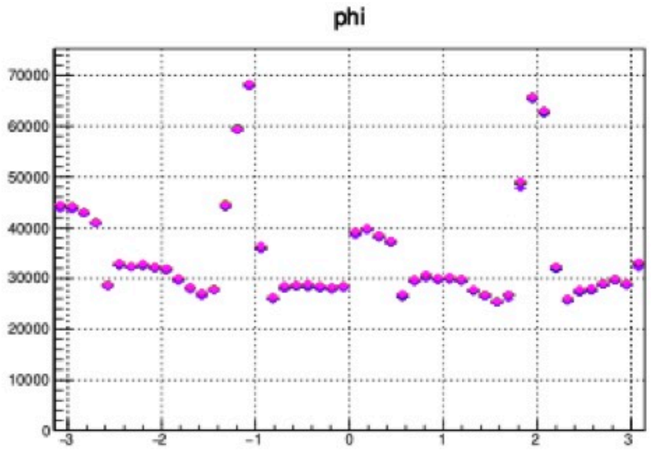
Vertex finding

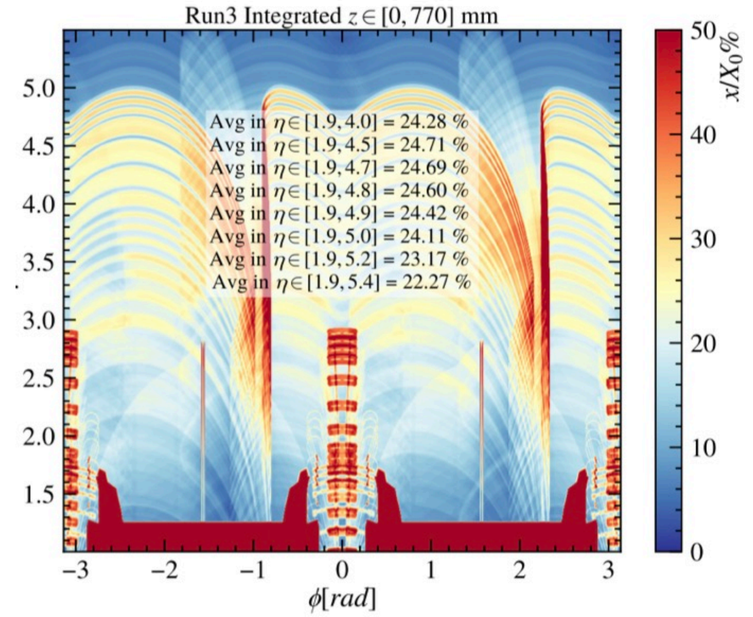


- Sort all tracks on their z intersection with the beam axis
  - Define regions in the histogram
  - Find vertices as the peaks in the given regions

Fake tracks

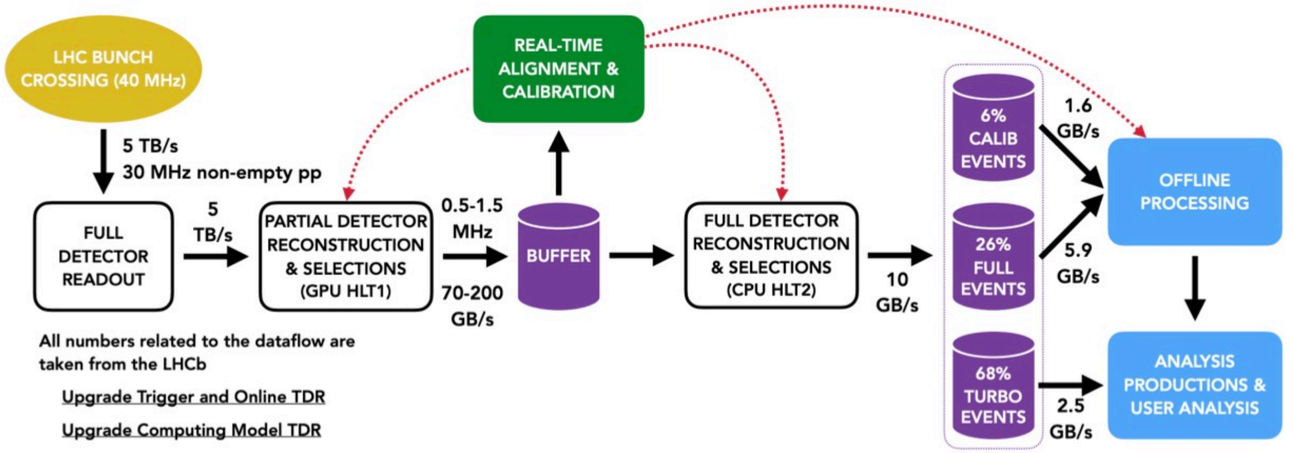
- Top plot taken from e.g. Wouter H. [slides]
  - Fake tracks visible in phi distribution
- Aligns with regions with a lot of material





Trigger overview

LHCb data-flow in Run 3



- Detector data received by O(500) FPGAs and built into events in the event building (EB) farm servers
- 2-stage software trigger:
  - HLT1: partial event reconstruction and coarse selection, reduces rate to ~ 1 MHz
  - HLT2: full event reconstruction and O(1000) selection lines
  - Buffering between HLT1 & HLT2 → real-time alignment & calibration
- After HLT2, 10 GB/s of data for offline processing