Standalone track reconstruction and matching algorithm for GPU based High Level Trigger at LHCb

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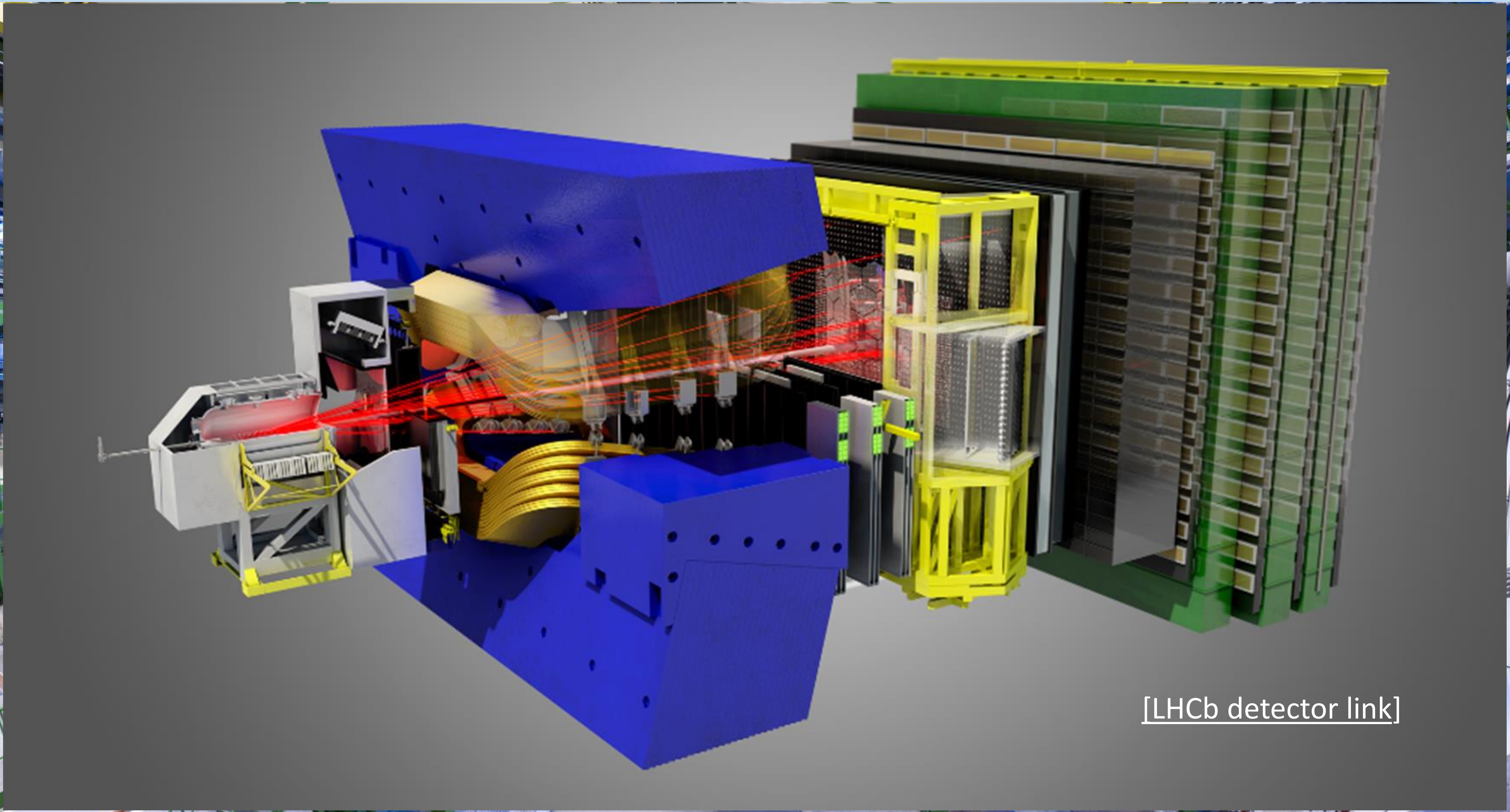
Arantza Oyanguren, Lorenzo Pica, Jiahui Zhuo
On behalf of LHCb colaboration

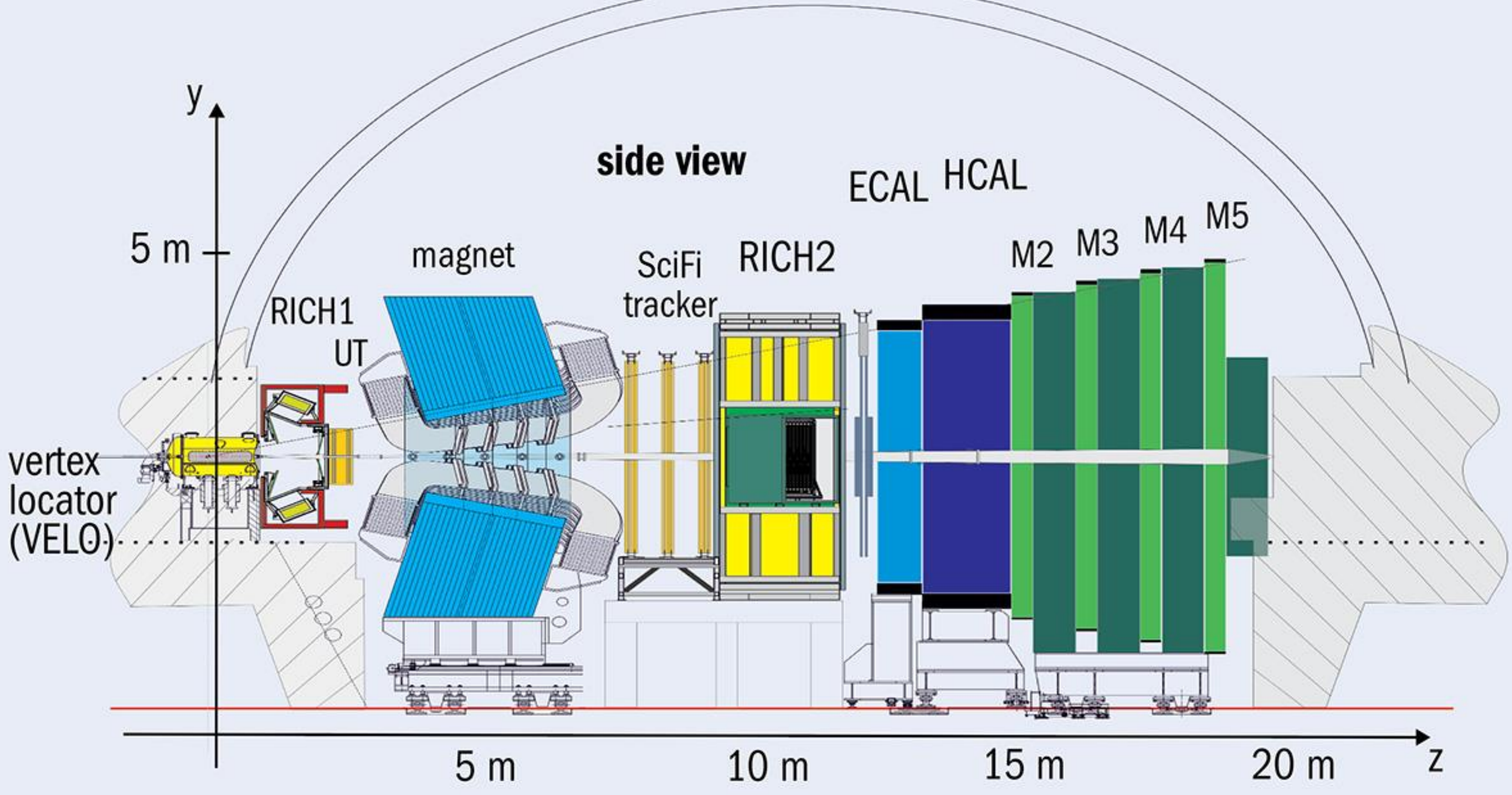
Introduction: LHCb detector



[LHCb detector link]

Introduction: LHCb detector

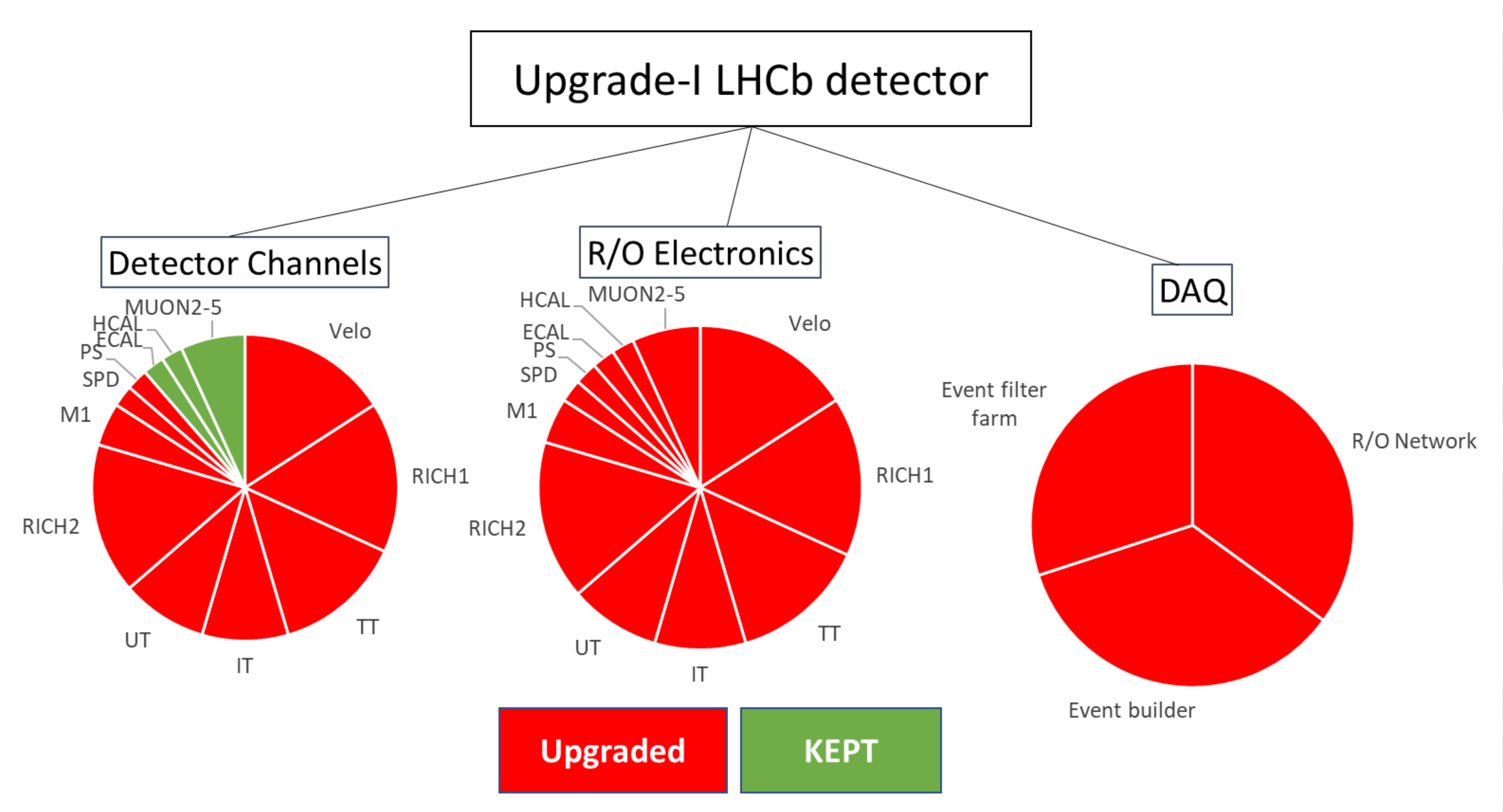
[CERN Courier: LHCb's momentous metamorphosis]



Upgraded LHCb detector for Run-3

- **5x** higher instantaneous luminosity 2x$10^{33} cm^{-2} s^{-1}$
- **10x** per unit time signal yield
- **6x** more pileup

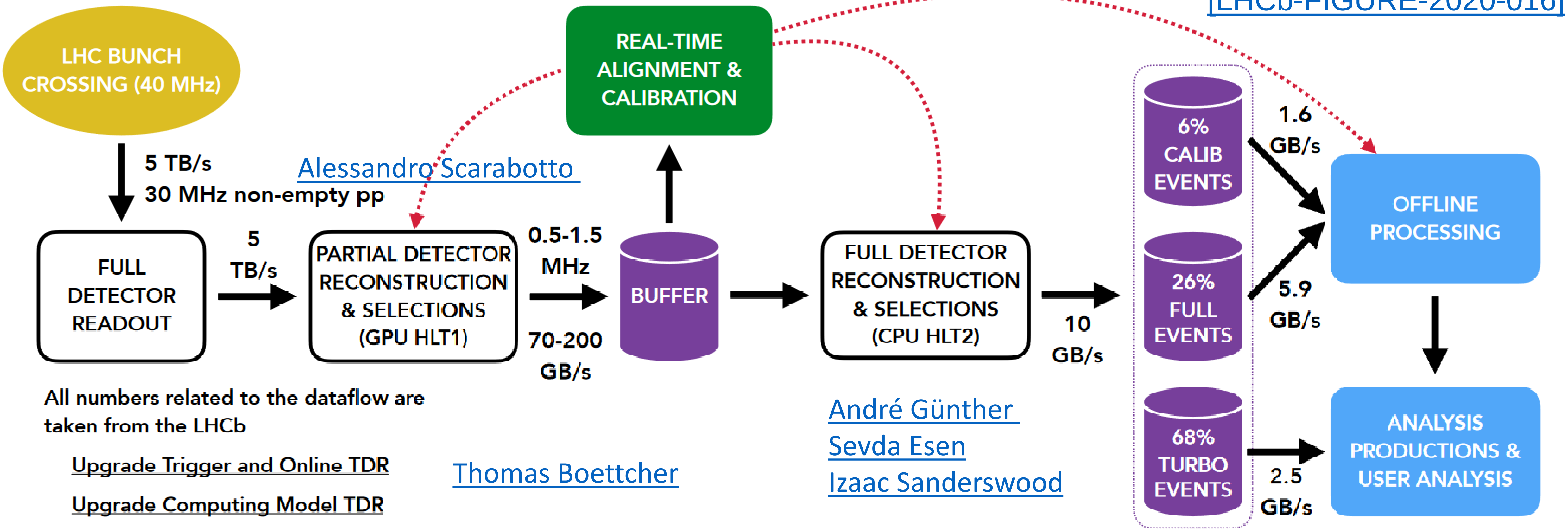
[LHCB-TDR-018]



Introduction: LHCb RTA data flow.

Real time alignment, talk by Florian Reiss

[LHCb-FIGURE-2020-016]



Alessandro Scarabotto

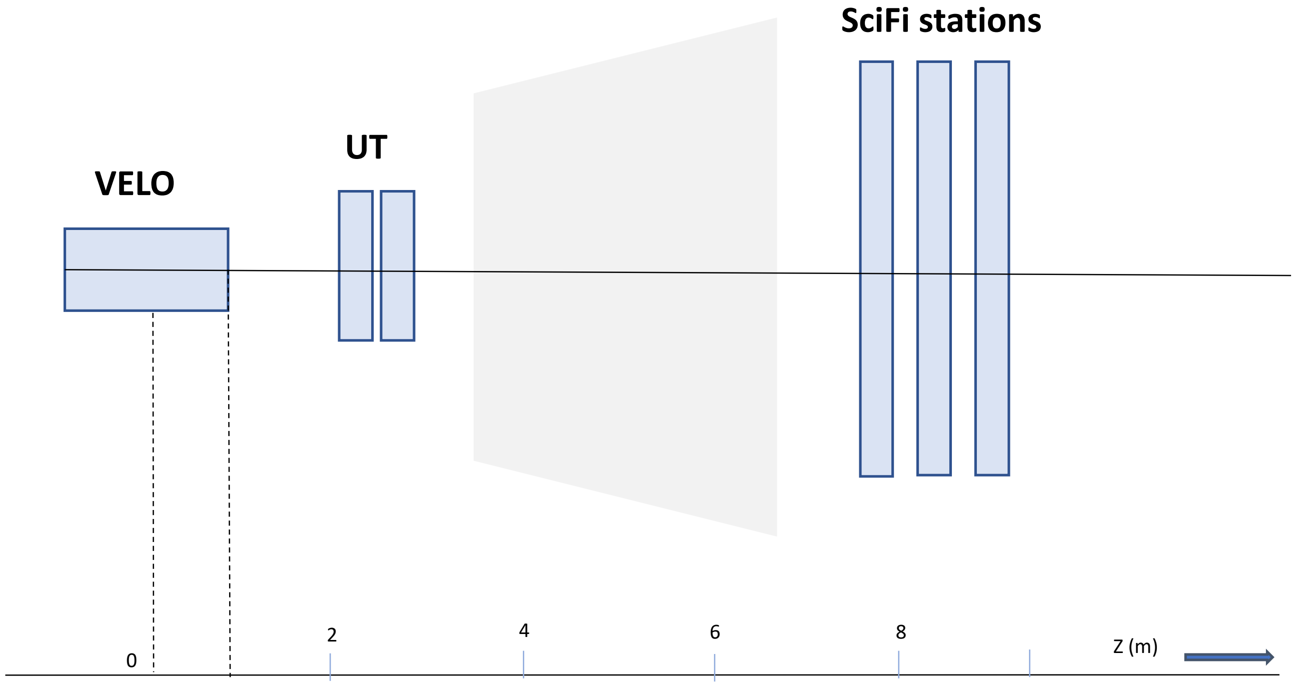
Thomas Boettcher

André Günther
Sevda Esen
Izaac Sanderswood

All numbers related to the dataflow are taken from the LHCb

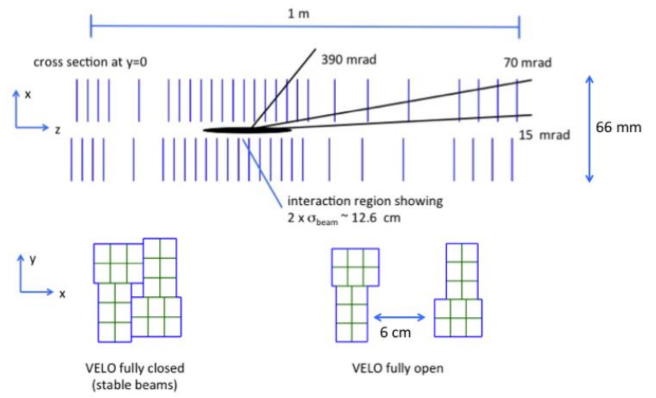
- Upgrade Trigger and Online TDR
- Upgrade Computing Model TDR

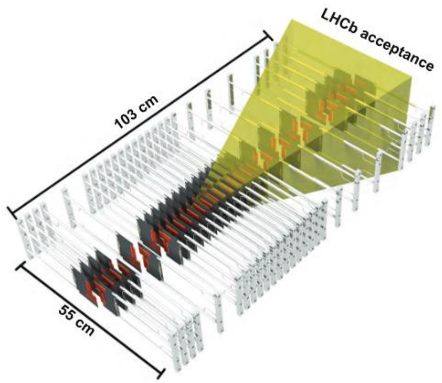
Introduction: Tracking system

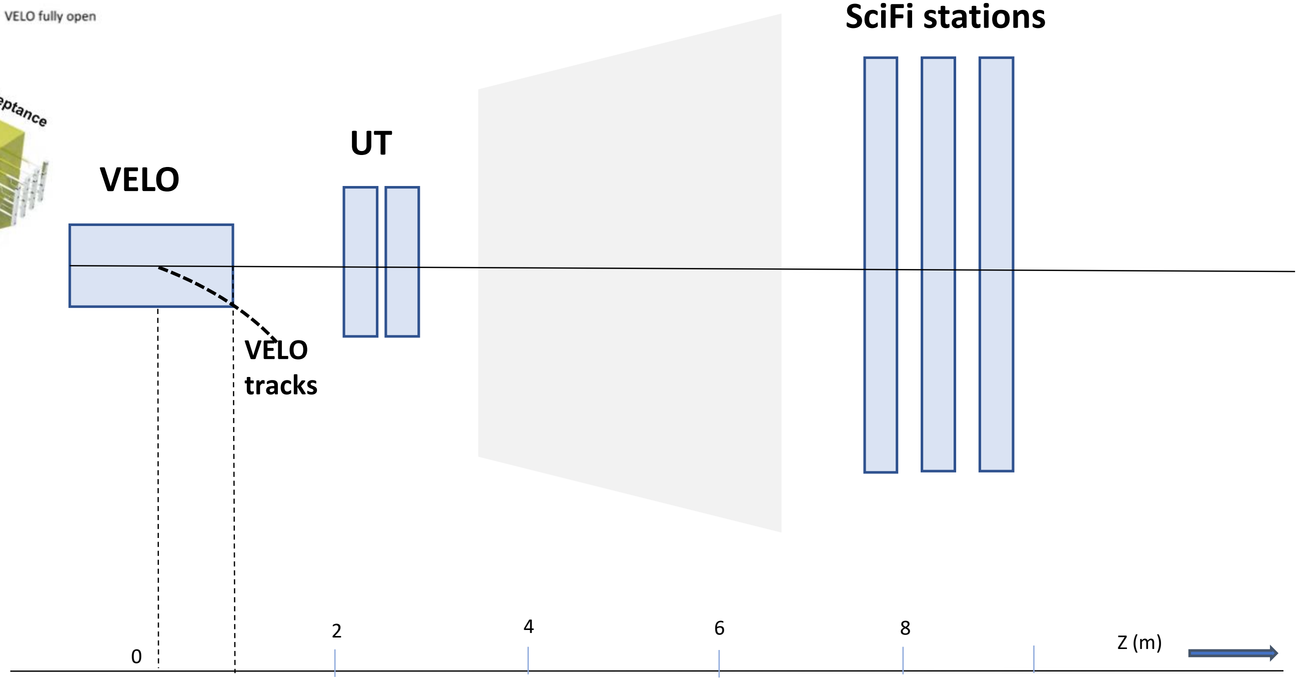


Introduction: Tracking system

VELO: Silicon pixel detector, 52 planes







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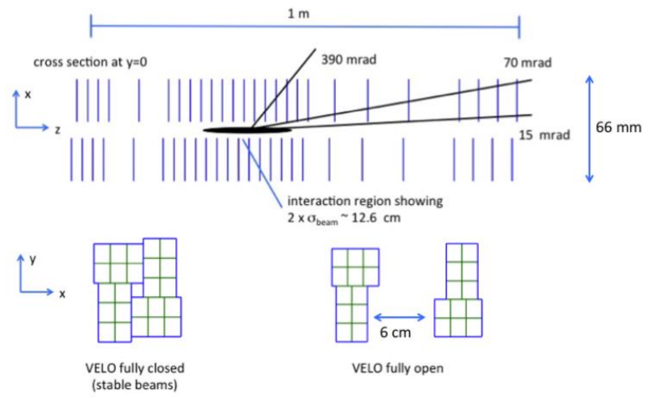
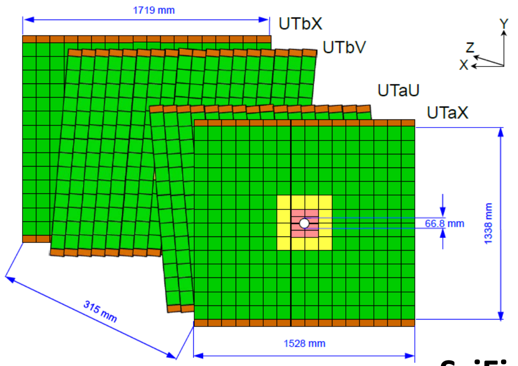
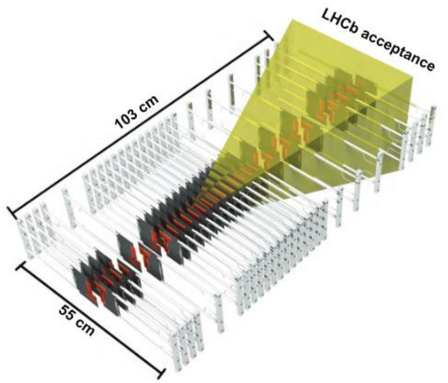
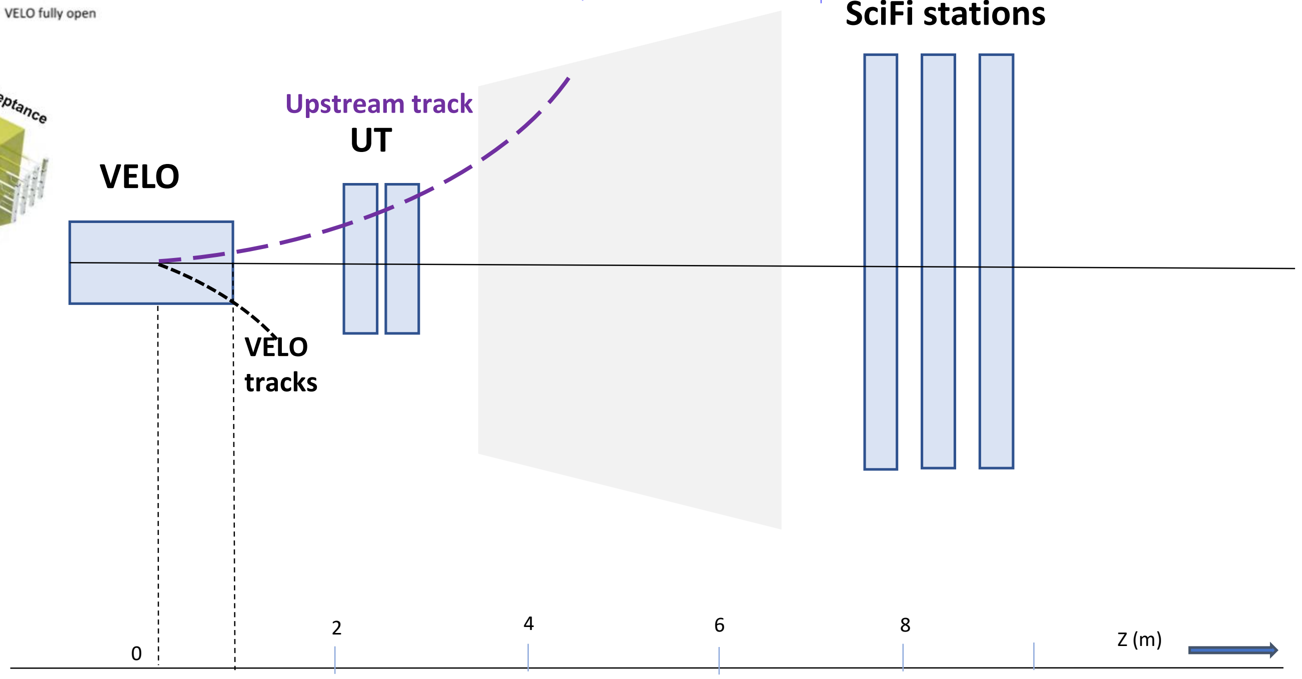


UT: Silicon strip detector, 4 planes







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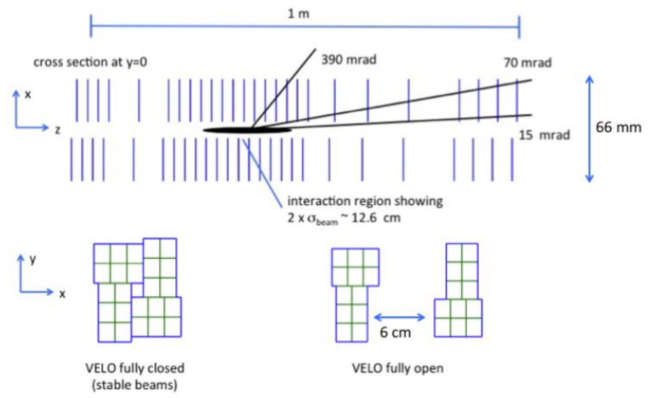

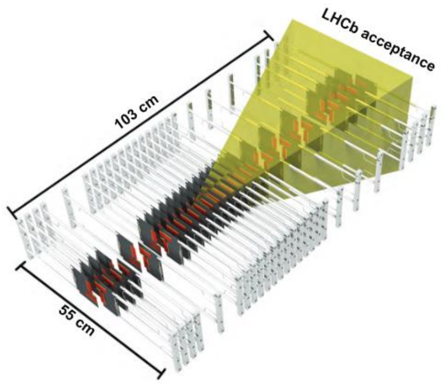

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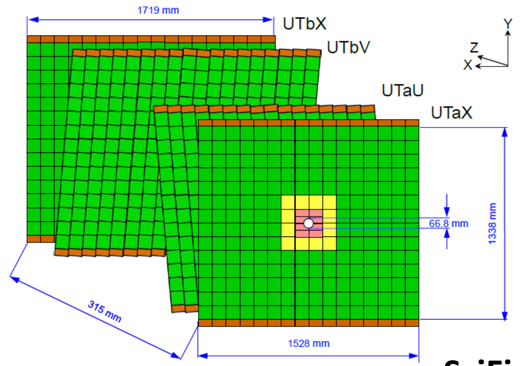
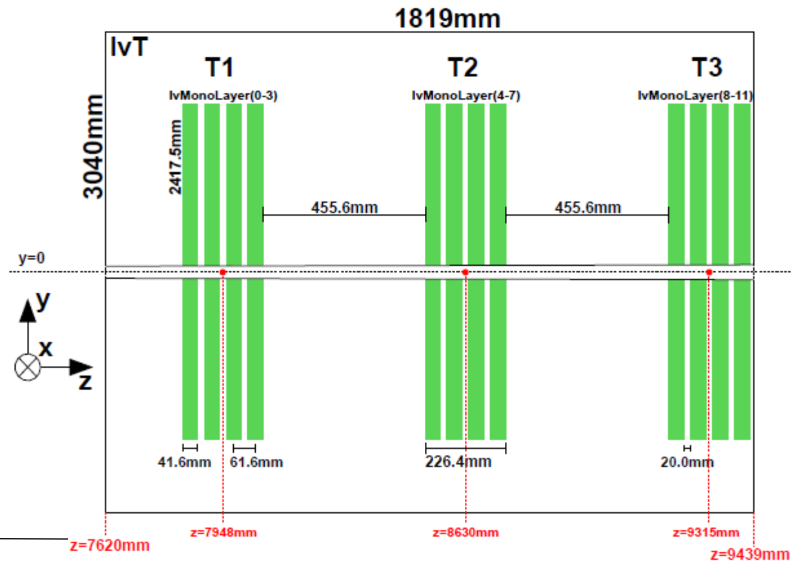
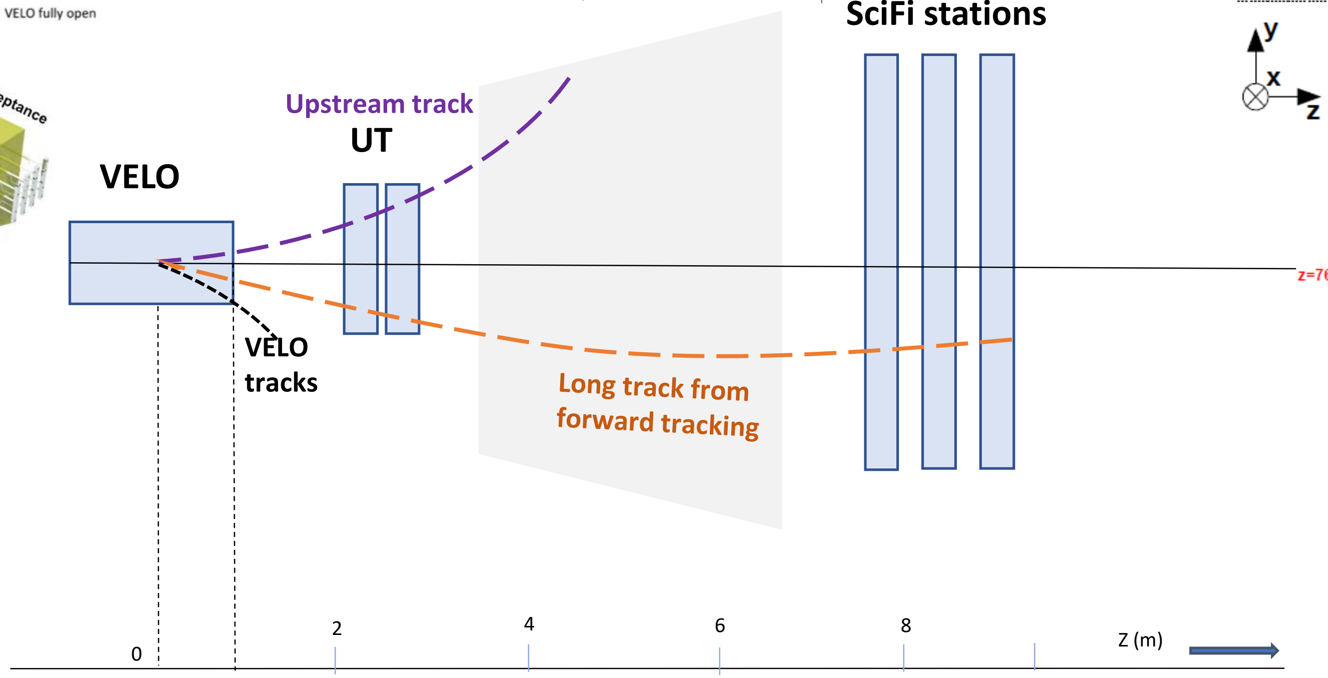


SciFi: Scintillating Fibre detector
(12 planes of 2x2.5 m long))

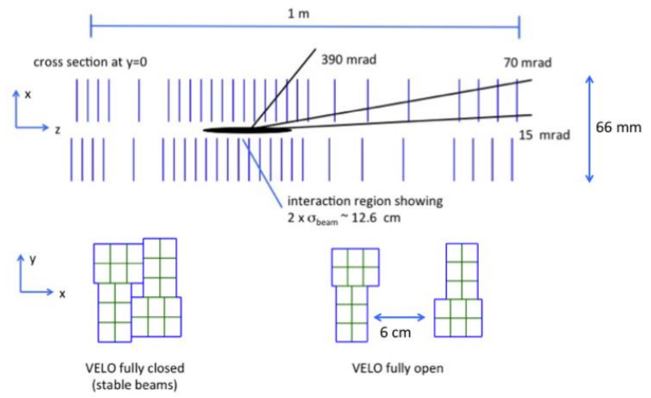




- 3 stations (T1, T2, T3) with 4 layers each in x-u-v-x configuration
- u and v-layers are tilted by a stereo angle of 5° in the vertical plane
- Two halves per layer with 5 modules (6 for T3) with 8 scintillating fibre mats

Introduction: Tracking system

VELO: Silicon pixel detector, 52 planes



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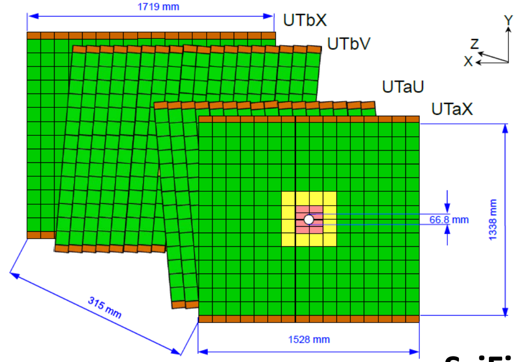

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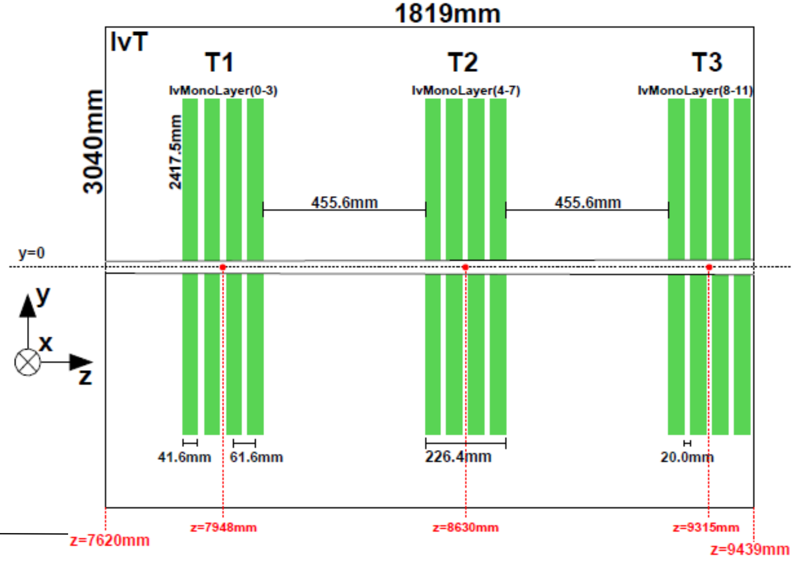

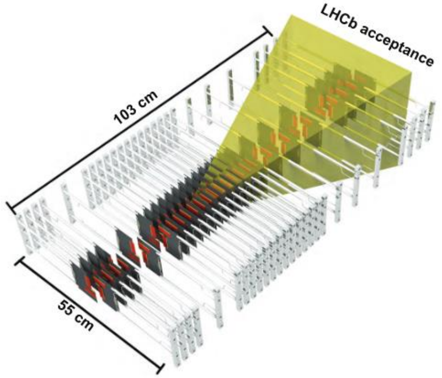

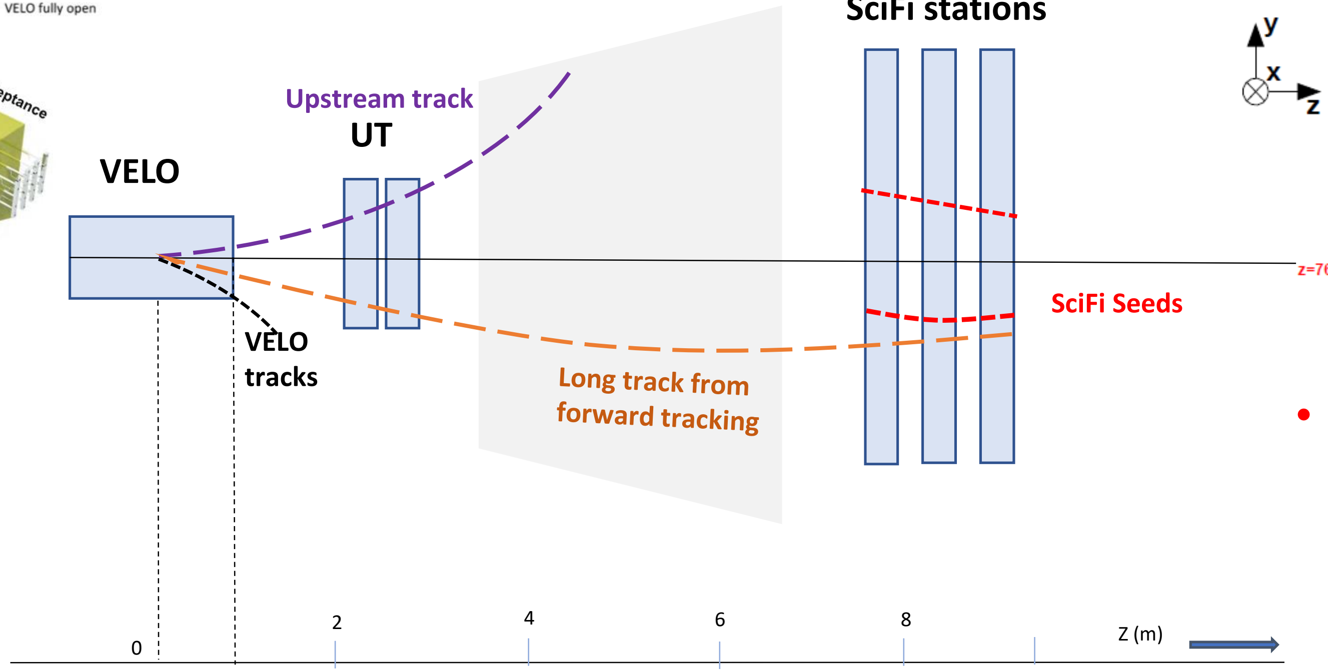

- Standalone SciFi Seeding at HLT1

Introduction: Tracking system

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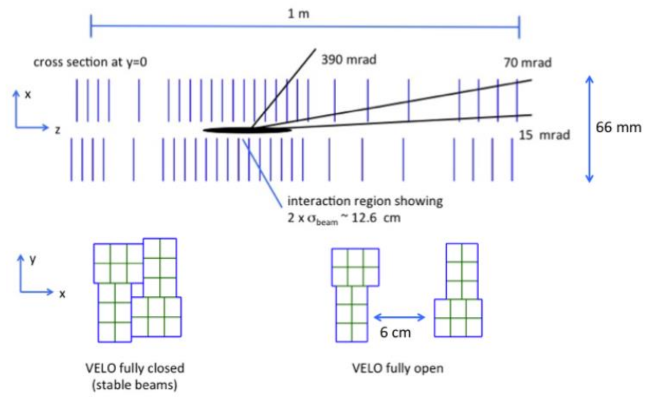

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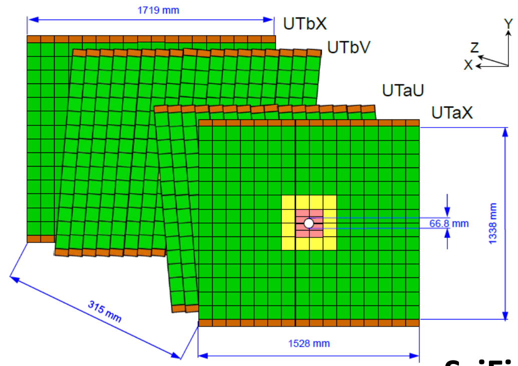

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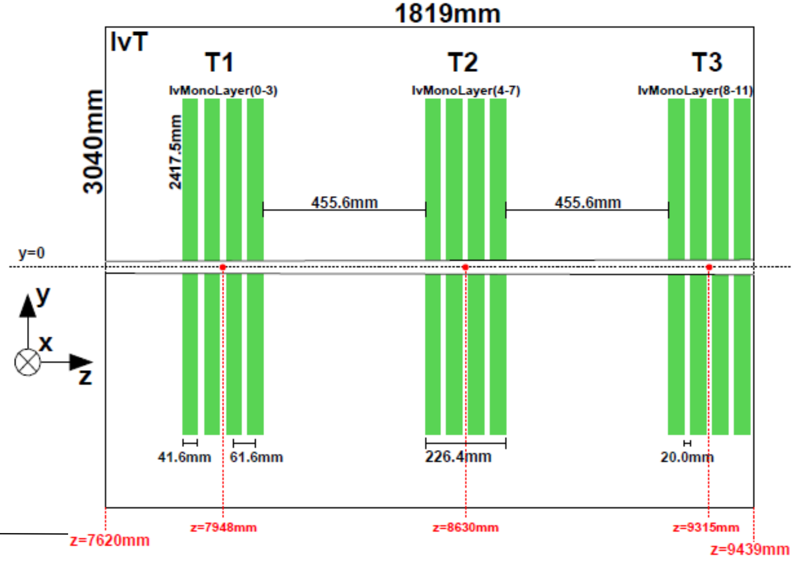
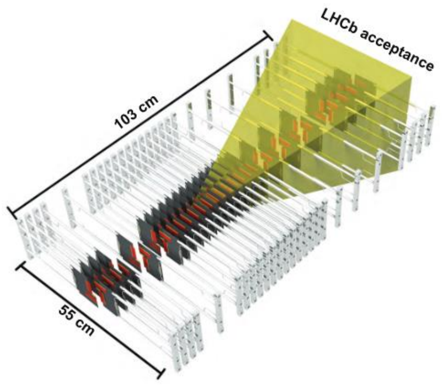
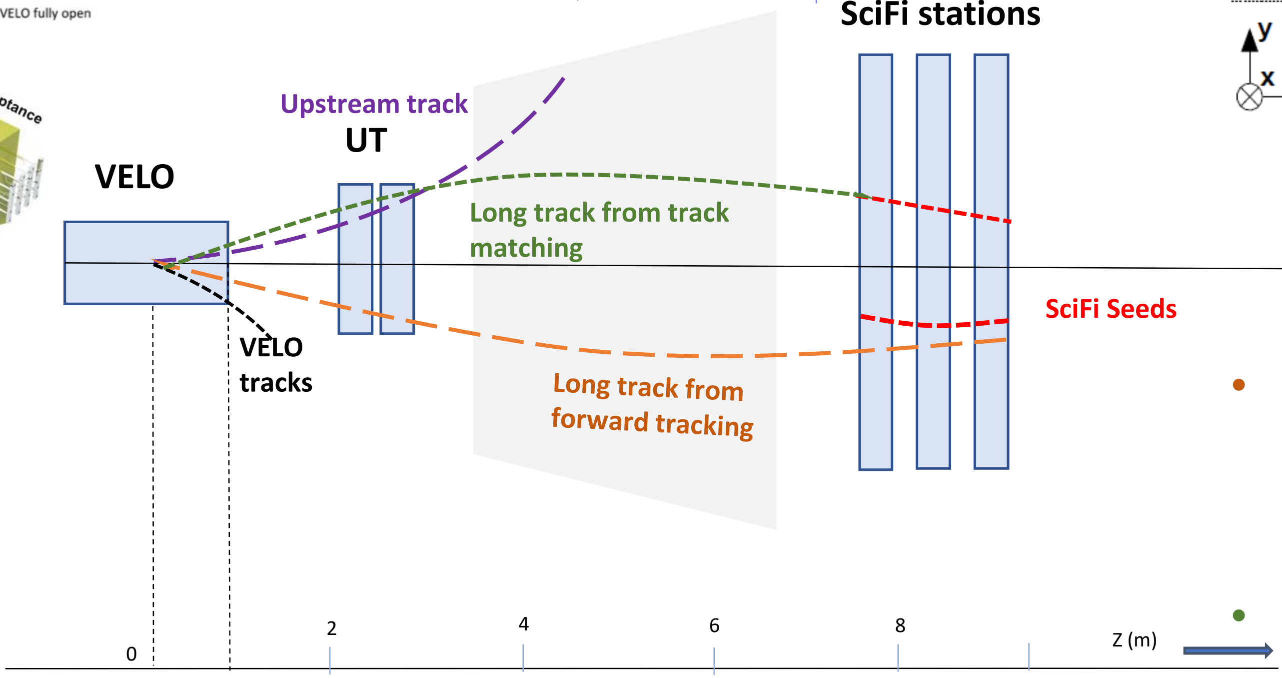


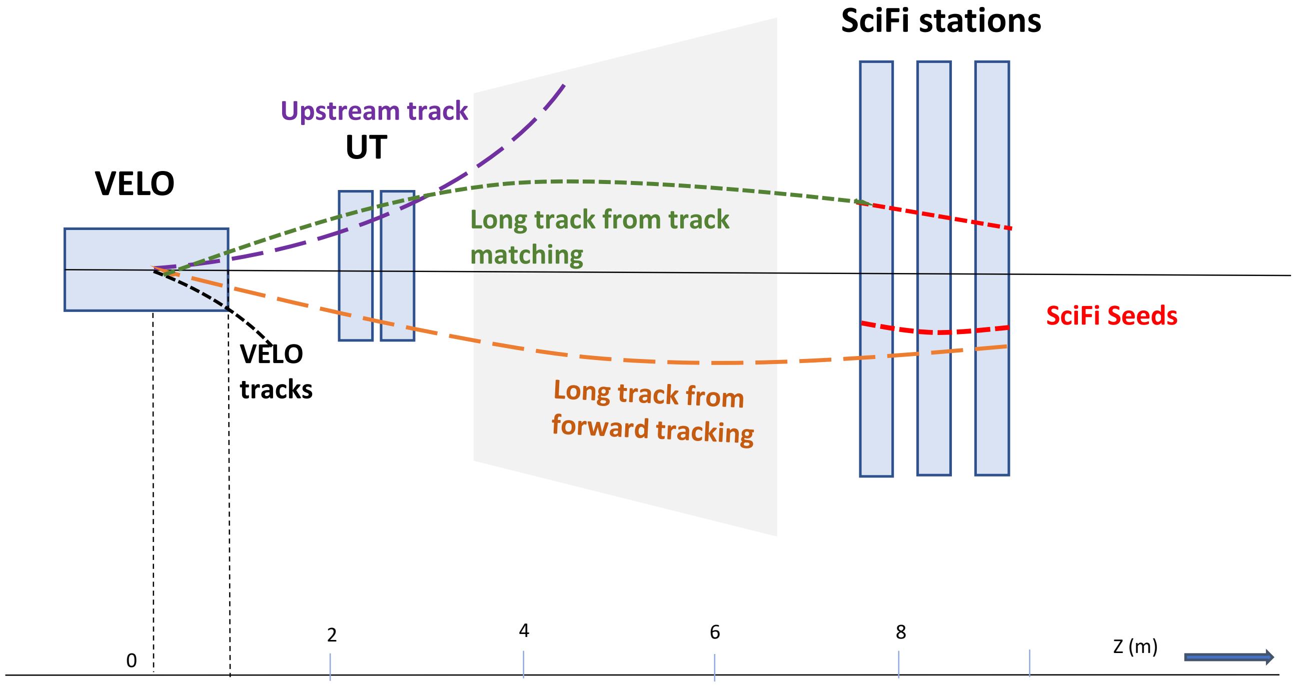




- Forward tracking: Velo tracks are extended to UT and then to SciFi to create long tracks (Baseline HLT1)
- VeloSciFi Track matching: SciFi seeds are matched with Velo tracks to create long tracks. (UT hits can also be added)

This talk is about two new algorithms implemented at HLT1 level on GPUs

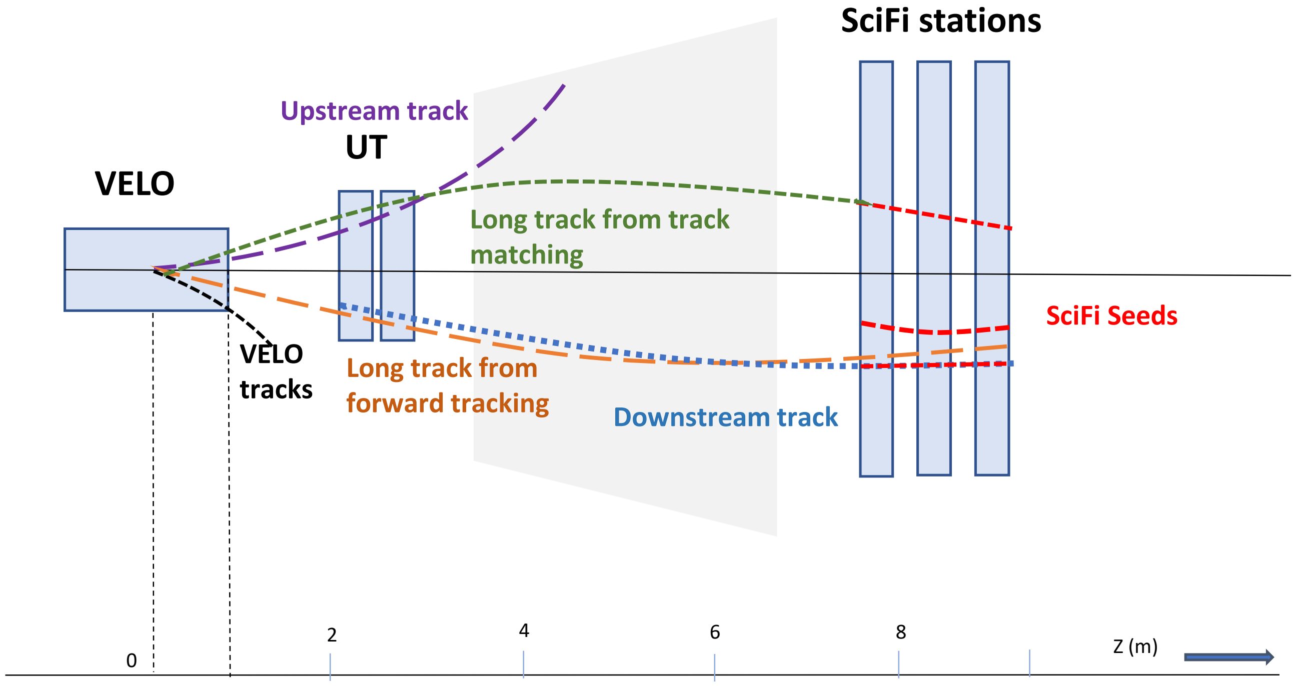
- Standalone SciFi Seeding
- VeloSciFi Track matching (Long tracks) (alternate to current forward tracking)



SciFi seeding

SciFi Seeds:

- +Velo tracks → produce Long tracks (Alternative to current forward tracking)
- +UT hits → produce Downstream tracks
- Help in ECAL PID (matching a track to a cluster helps distinguish electrons from photons).
- Extending physics reach of LHCb – See talk by Izaac Sanderswood



- Standalone SciFi seeding algorithm in HLT1
  - ✓ 12 layer with ~450 hits each (average)
  - ✓ Residual magnetic field and 3 stations spread over 1.8 meters
  - ✓ Fibers 2.7 meters long

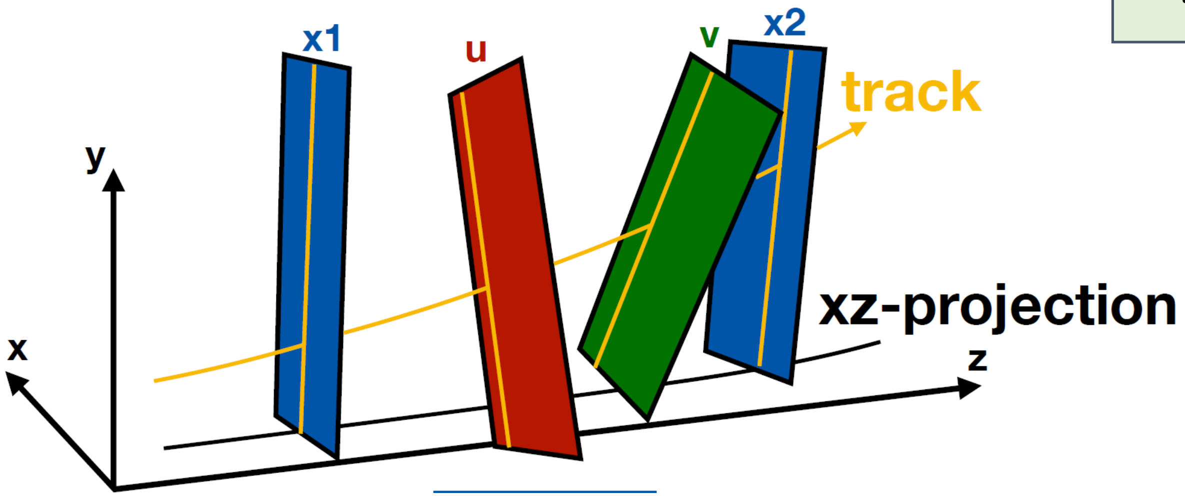
- Two cases optimized for varying initial layers to account for hit inefficiencies

- Each iteration consists of two main components of algorithm

  Seeding_XZ

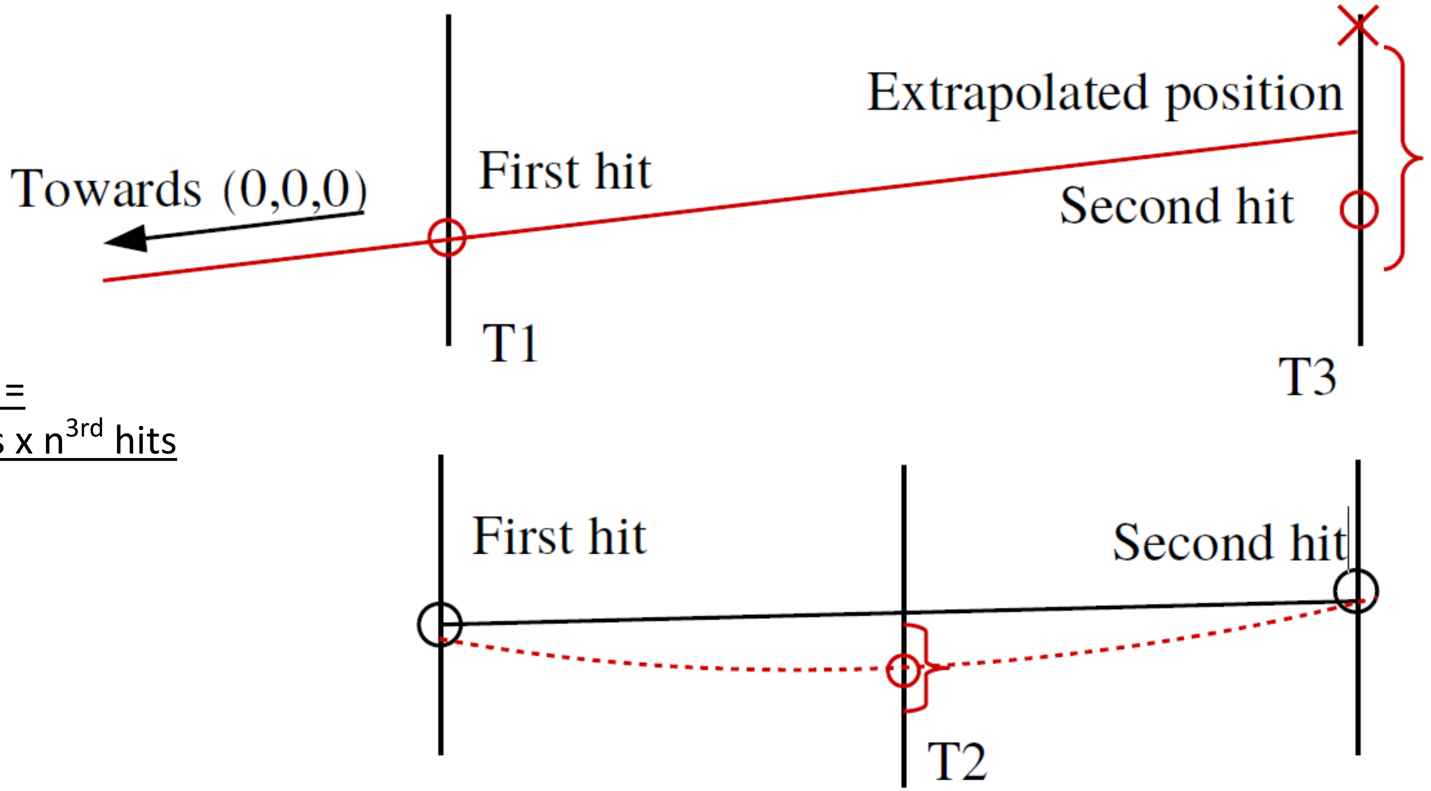
  Seeding_confirmTracks

SciFi hits
⇩
SciFi Seed_XZ
⇩
Add UV hits to confirmTracks
⇩
SciFi seeds



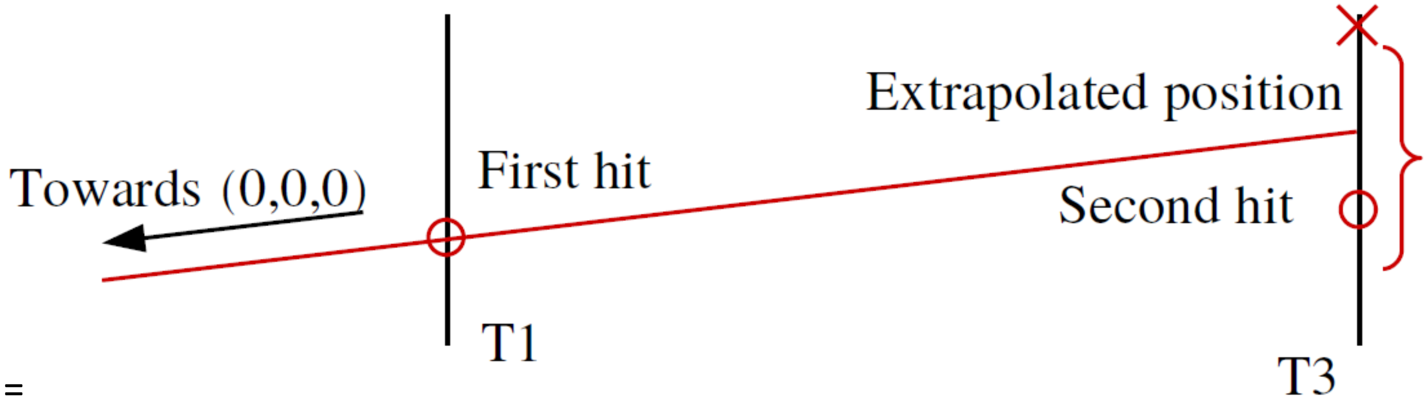
SciFi seeding: *Seed_XZ*

SciFi Hits ⇨ Doublets searched in T1 & T3, (P > 3Gev/c & origin at 0,0,0) ⇨ for each doublet charge-momentum estimation, narrower window for 3rd hit ⇨ 3 hit combinations with hits from T2 station, taking bending into account



XZ combinatorics =
n^{1st} hits x n^{2nd} hits x n^{3rd} hits

SciFi Hits → Doublets searched in T1 & T3, (P > 3Gev/c & origin at 0,0,0) → for each doublet charge-momentum estimation, narrower window for 3rd hit → 3 hit combinations with hits from T2 station, taking bending into account → 3 hit + Parabola with cubic correction estimation on MC to predict positions in the remaining layers → Add remaining hits, accept candidates with at least two additional hits from remaining layers i.e min 5 out of 6 possible hits → Build 3x3 matrix for track fit with all contributing hits, reject track candidates with $\chi^2/ndof$ worse than a fixed value (<6) → Seed_XZ candidates



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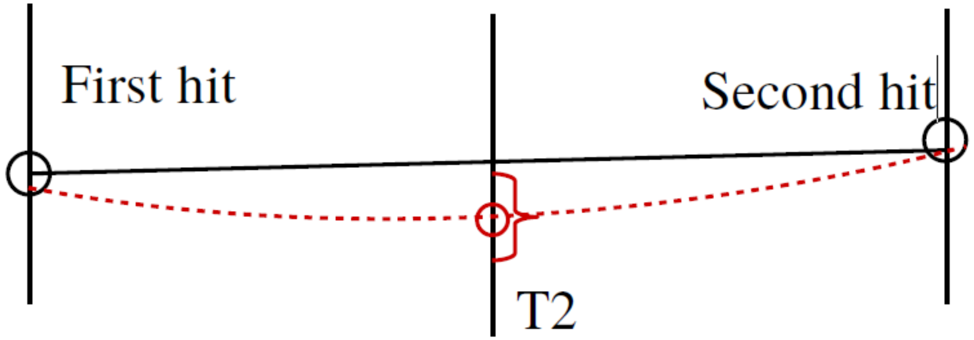


Seed_XZ candidates

- Still need to remove ghosts (still around 50-60% of XZ segments)
- Need to measure parameters of the track

Seeding_confirmTracks: Add U/V hits (6 hits)

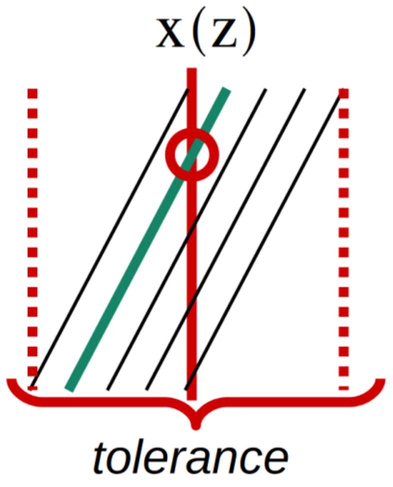
1. For each XZ segment, open a very large tolerance window in y for initial UV-layer .
    - Many different fibres (black) cross a given x(z) hypothesis (red).
    - Each fibre crosses that hypothesis at a different y, giving a y measurement.

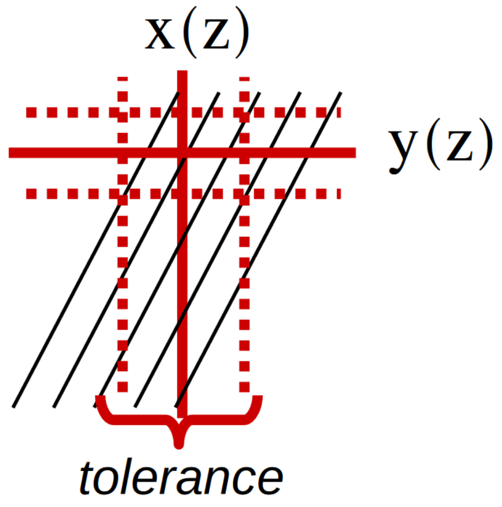
2. For all hits collected in that window, determine the corresponding y and $t_y \rightarrow$ *y(z).*

3. For all other layers, open a much narrower tolerance window around that hypothesis update t_y at each hit found.

4. Accept the tracks with at least 4 hits in UV

5. Fit the candidates with a linear model in Y and keep the ones with best χ^2

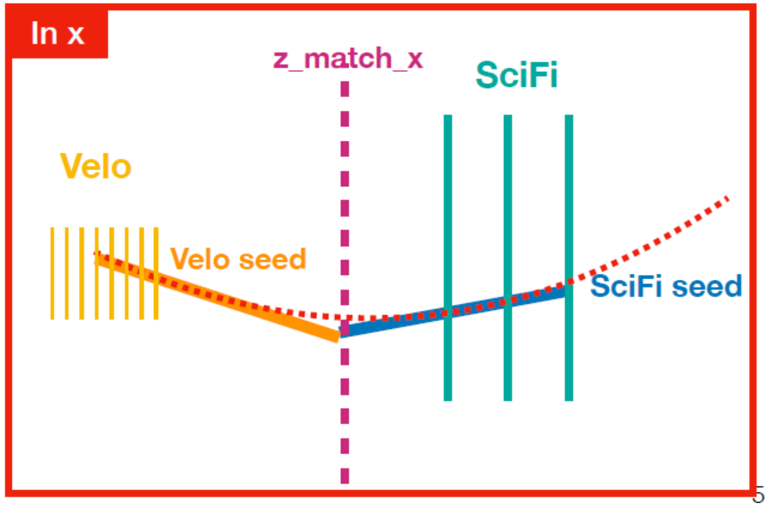


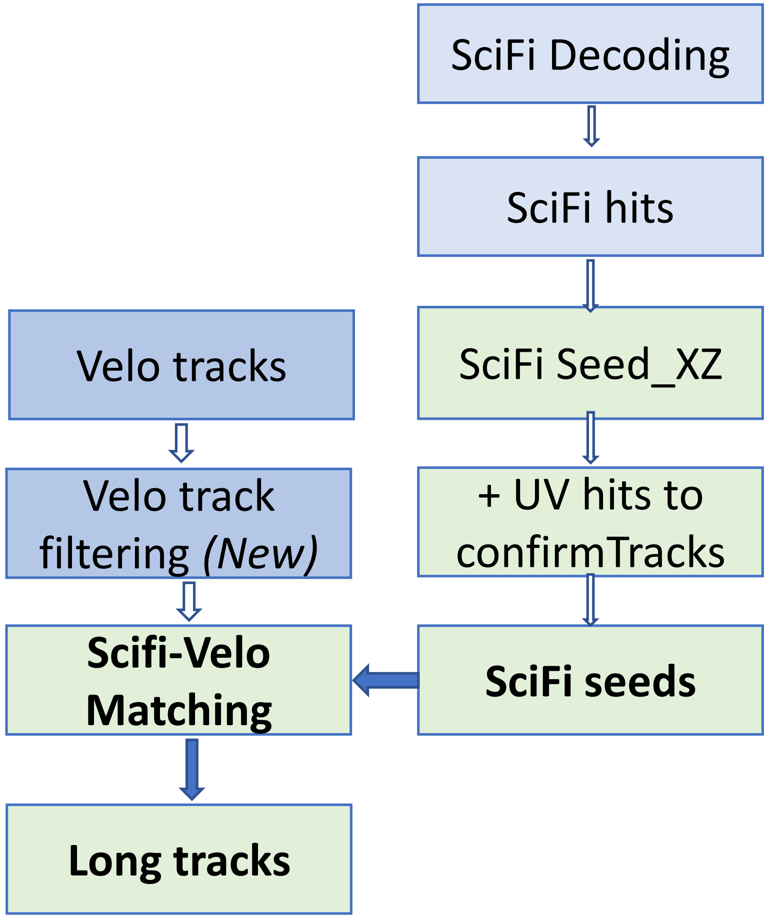


Track Matching (SciFi + Velo)

Algorithm approach:

- SciFi seeds O(80) matched to Velo tracks O(100) without UT hits
- Start with SciFi seeds and parallelize over SciFi loops
- Velo/SciFi seeds extrapolated to magnet as lines ("Kink" approximation)
- Magnetic field and bending in *y* is parametrized with simulation
- Minimal requirements on χ^2 and slope to reduce combinatorics and fakes
- Clone killing: tracks that share a VELO track are compared and only the one with the best χ^2 is kept

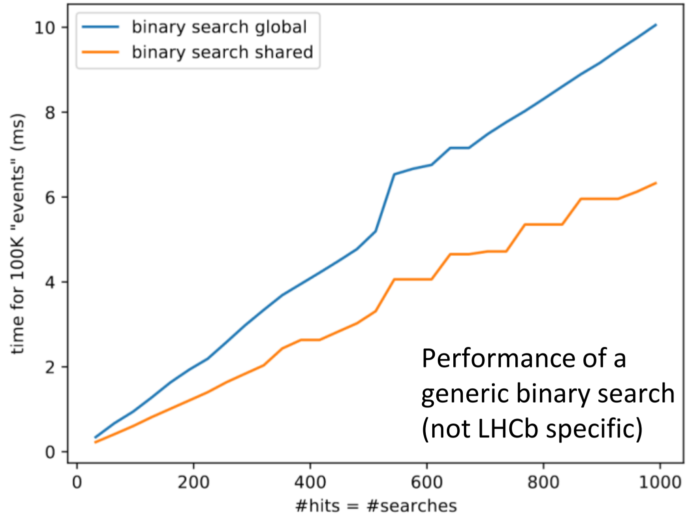


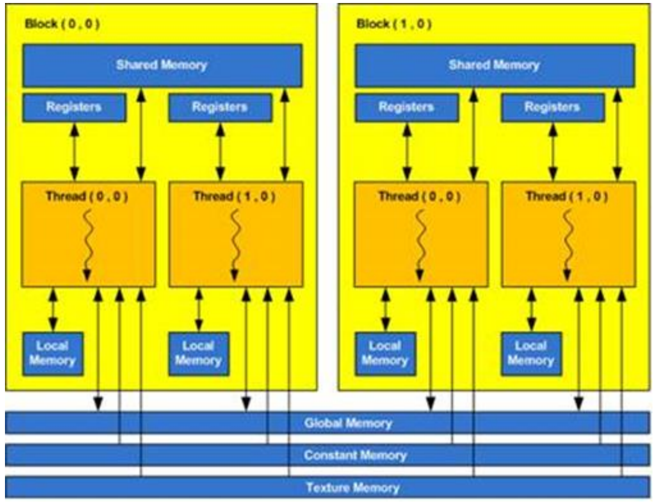


GPU implementation

GPU implementation features for both SciFi seeding and Track Matching

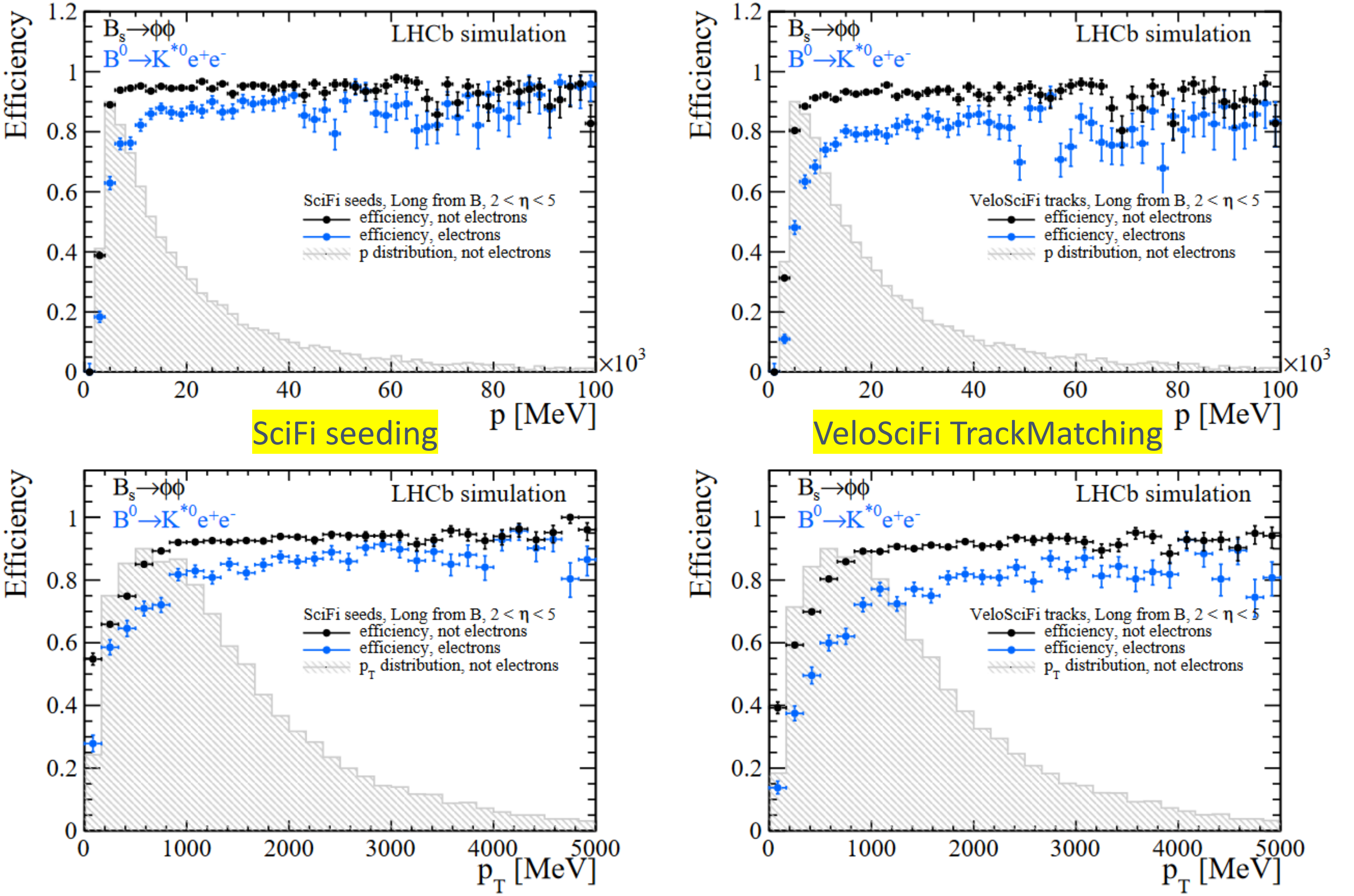
- ✓ Event level parallelization from framework
- ✓ Minimized global memory usage
  - ✓ SciFi hits caching preferred in shared memory of GPU which is faster as compared to global memory
- ✓ For each XZ track in parallel, collect UV hits in 2 different layers
- ✓ Binary search implementation for making pair candidates from hits
- ✓ Optimal block size on A5000 (64 KB shared + 32 KB L1 configuration)
  - ➢ 8kb of shared memory per block => 4 warps per block (128 threads)
- ✓ Simplified approach in the confirm_track step to add UV information as compared to HLT2
- ✓ For clone killing using a shared memory voting algorithm,
  - ✓ For each track candidate in parallel, compute a score based on χ^2 and make decision for rejection of clones





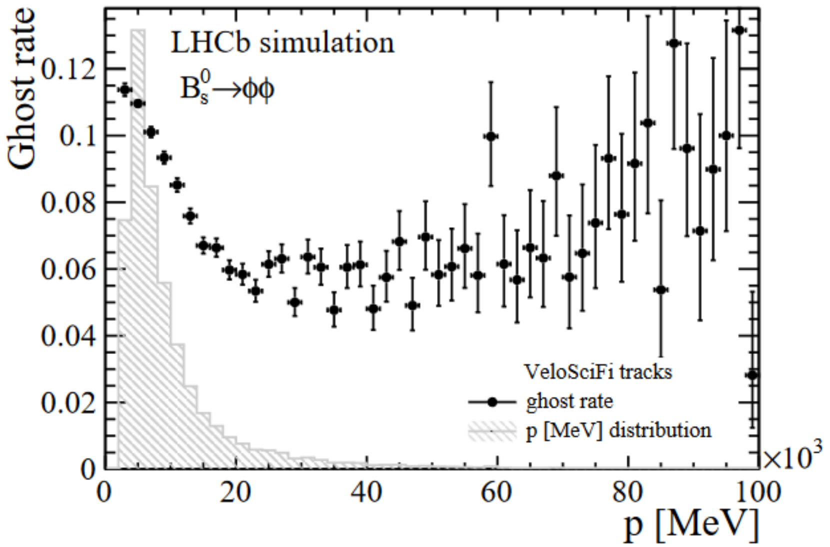
Efficiency

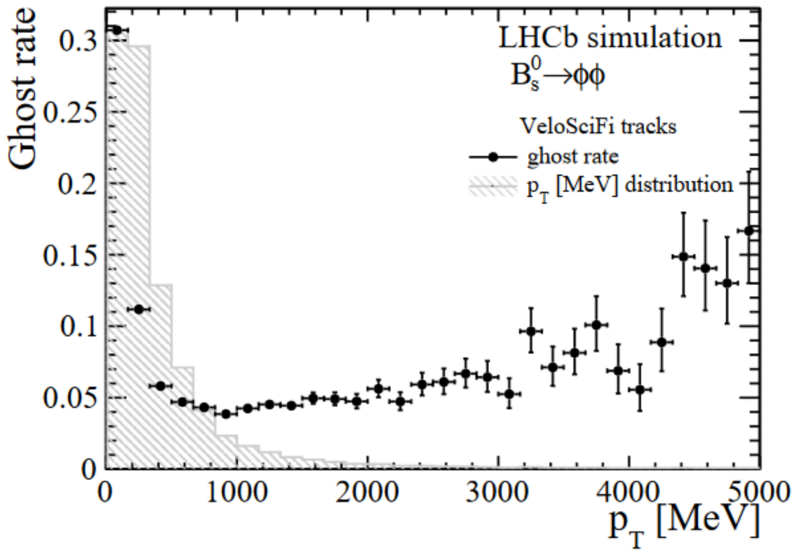
- long tracks from B decays (p > 5GeV): ~83% (92%) –
- long electrons from B decays (p > 5GeV): ~ 70% (75%) –
- Increased efficiency w.r.t the baseline approach without cuts on p_T.



SciFi seeding

VeloSciFi TrackMatching

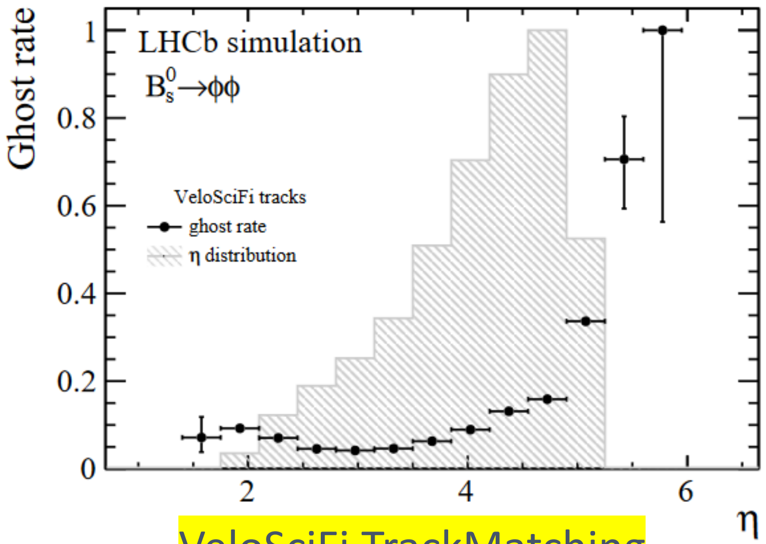




Ghost rate

~9% for all reconstructed tracks

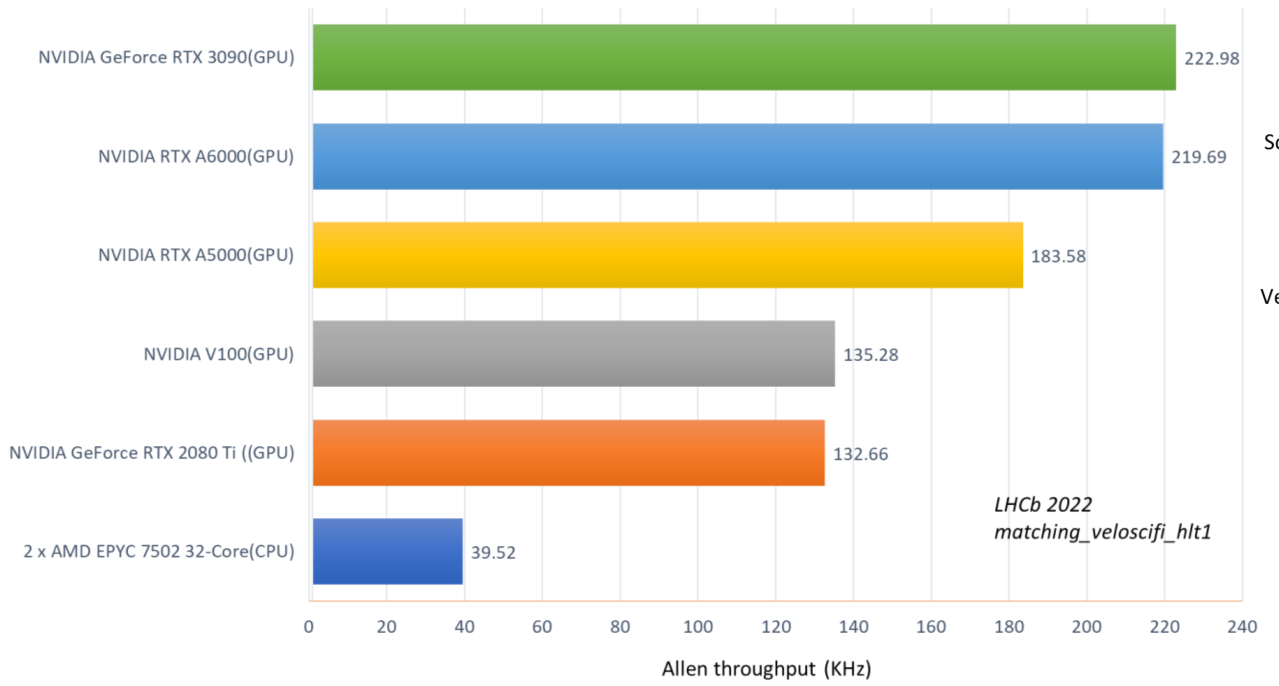
~5% for p > 3GeV, P_T > 0.5GeV

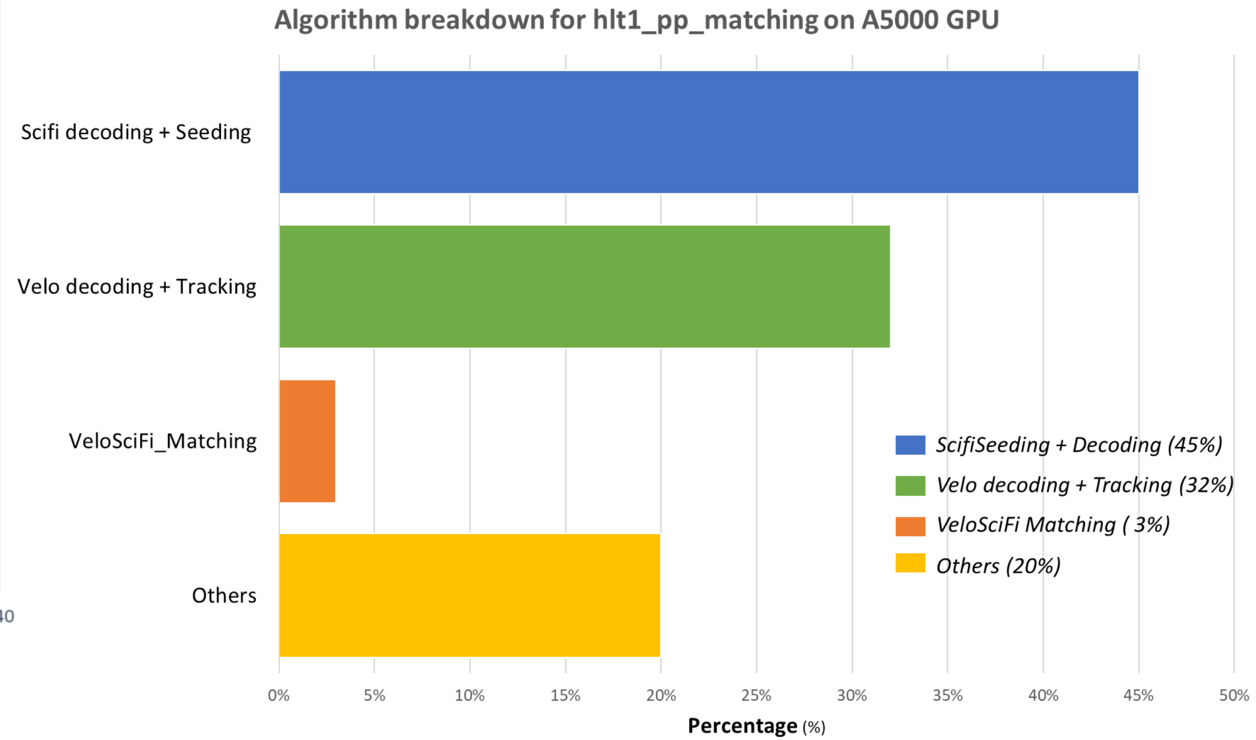


VeloSciFi TrackMatching

Performance (Throughput)

[LHCb-FIGURE-2022-010]

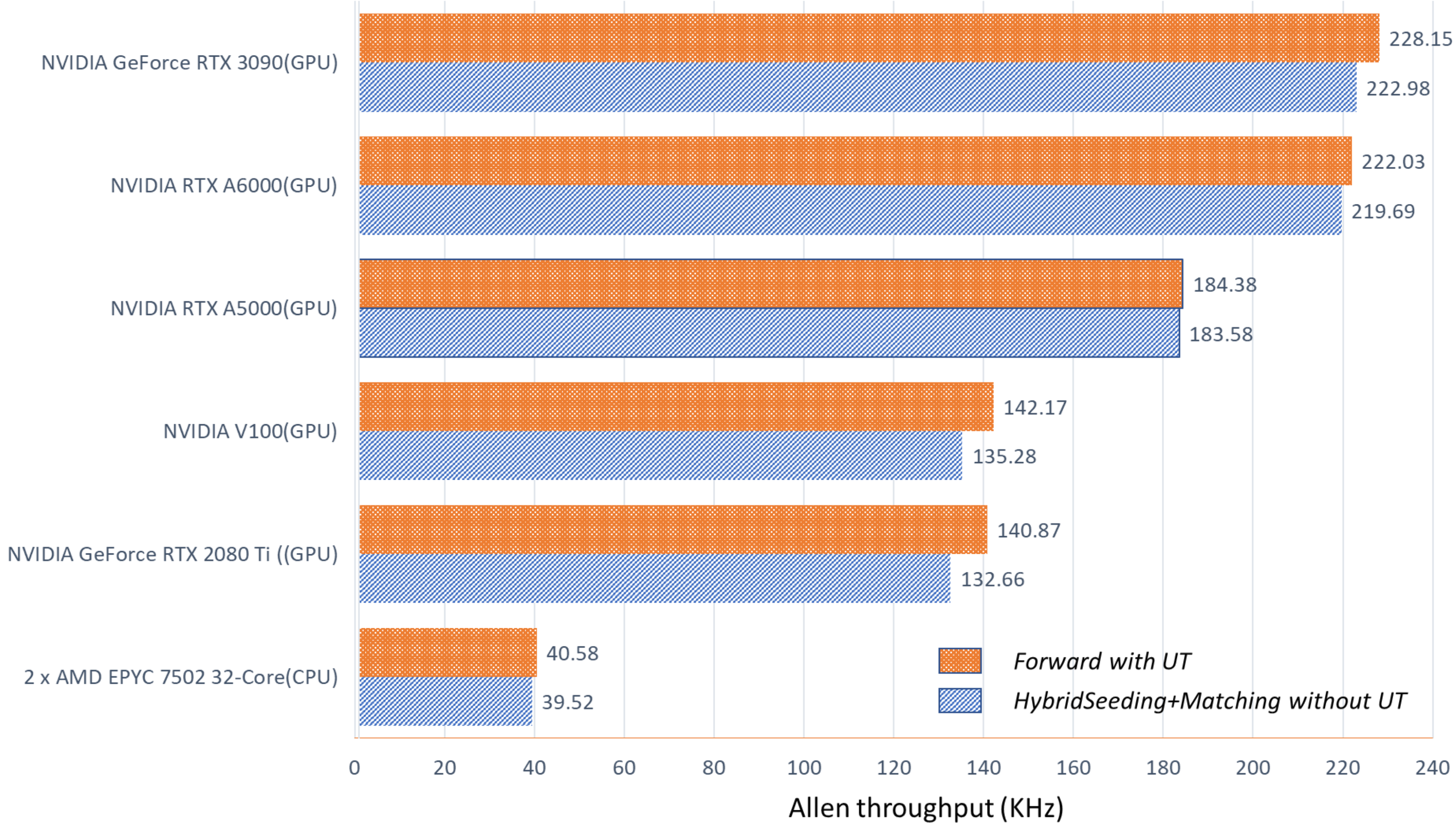




Performance (Throughput)

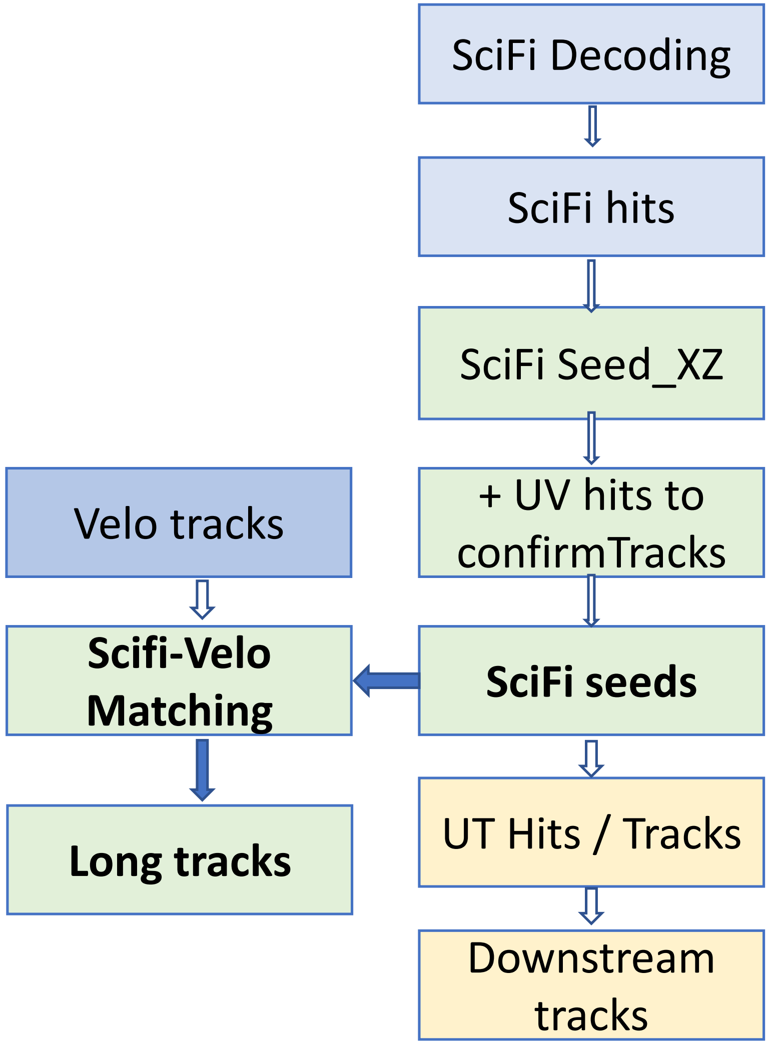
[LHCb-FIGURE-2022-010]

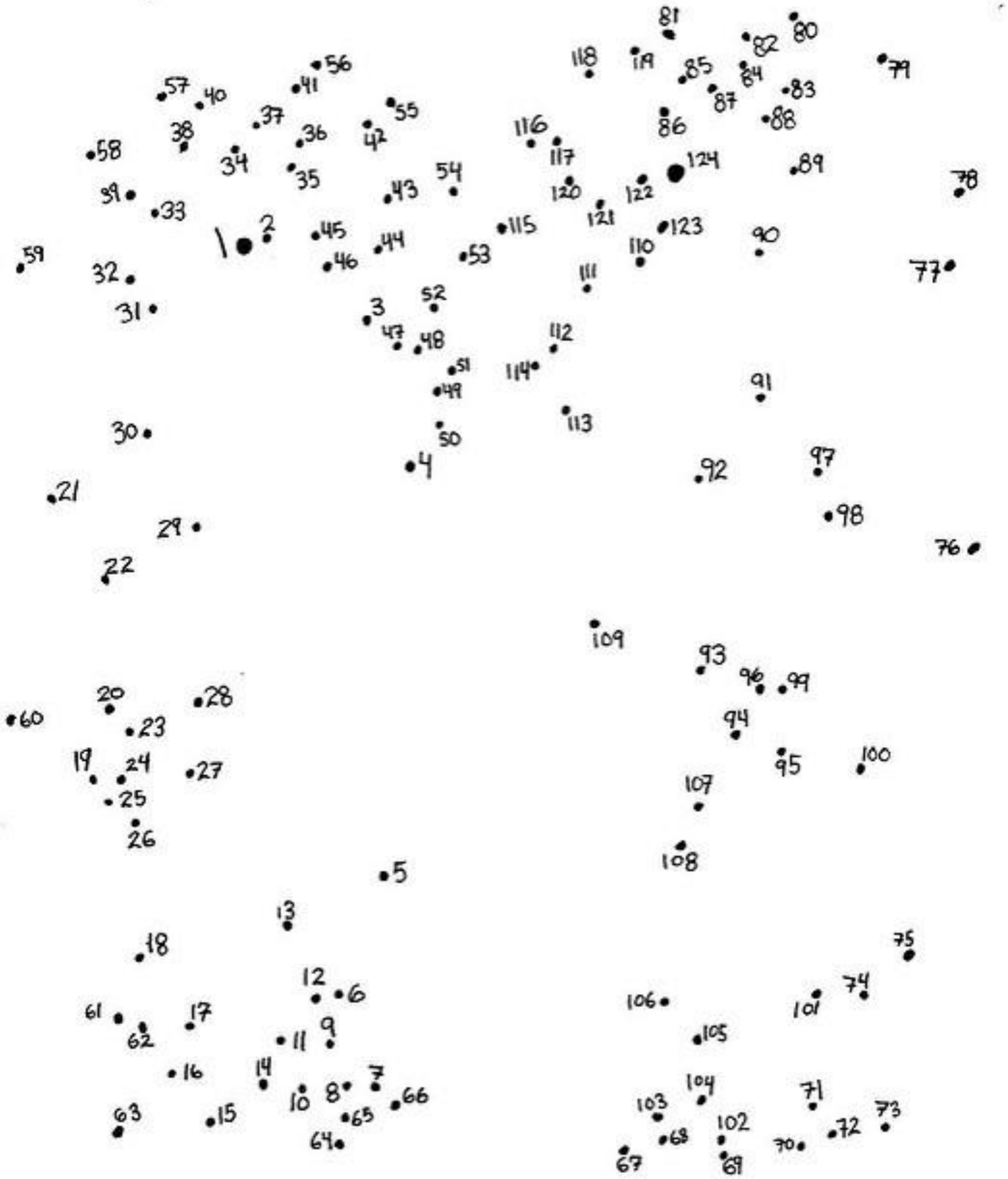
For details of HLT1 see talk by Alessandro Scarabotto



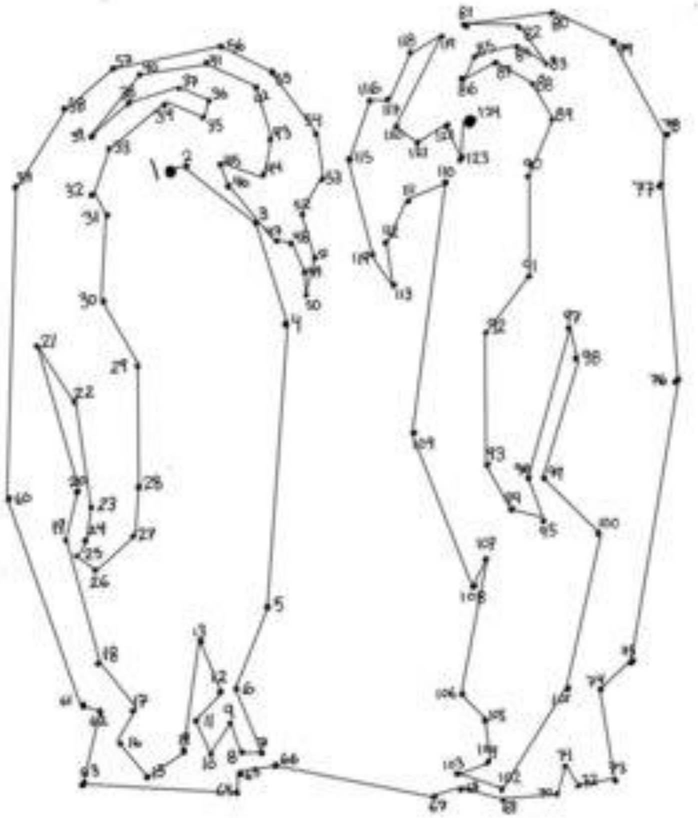
Summary

- Presented a new GPU-based Scintillating Fibre seeding algorithm for HLT1 at LHCb.
- An alternative long track reconstruction based on SciFi seeds + Velo track matching.
- Comparable throughput with Forward-with-UT, similar efficiencies at high momentum, without any hard cut at low p_T.
- Now we have SciFi seeds in HLT1 which are basic building blocks for downstream tracking.

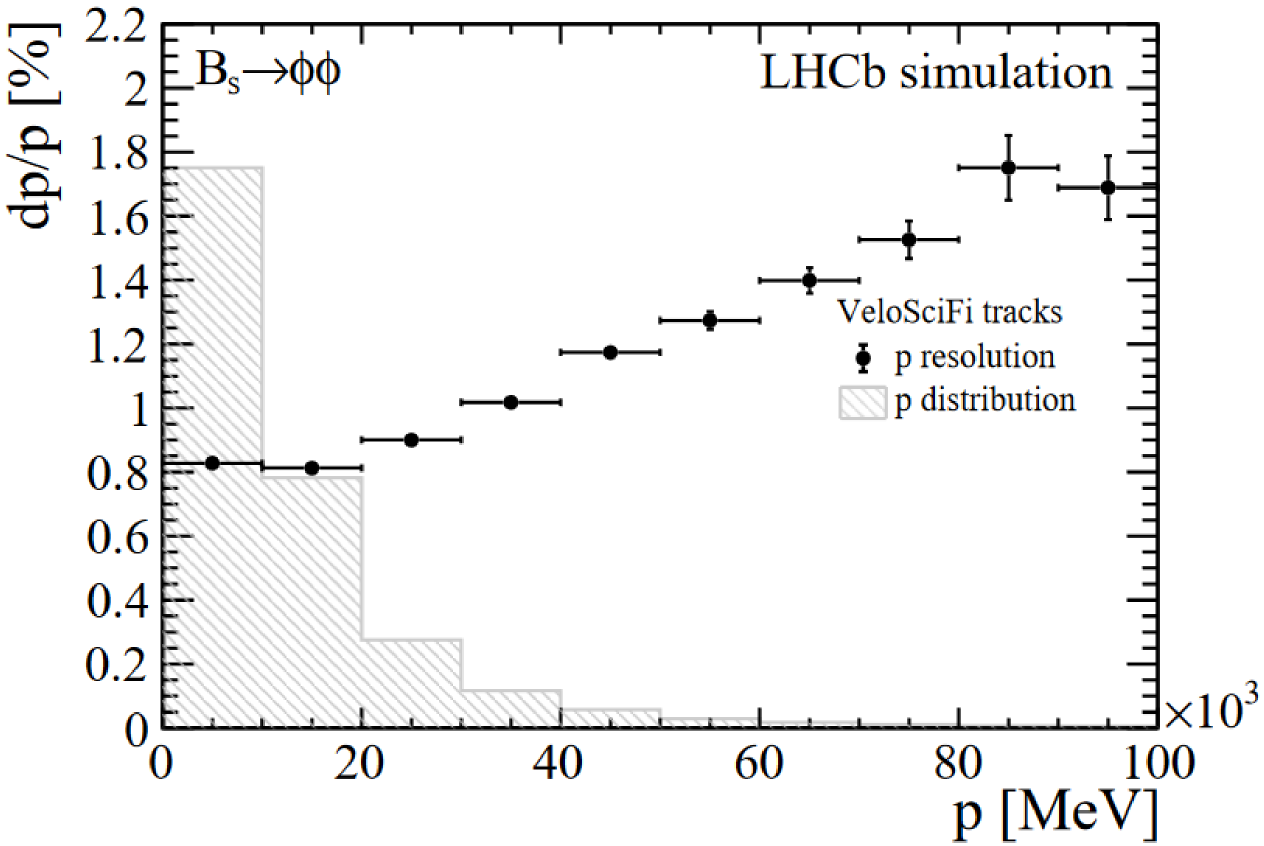




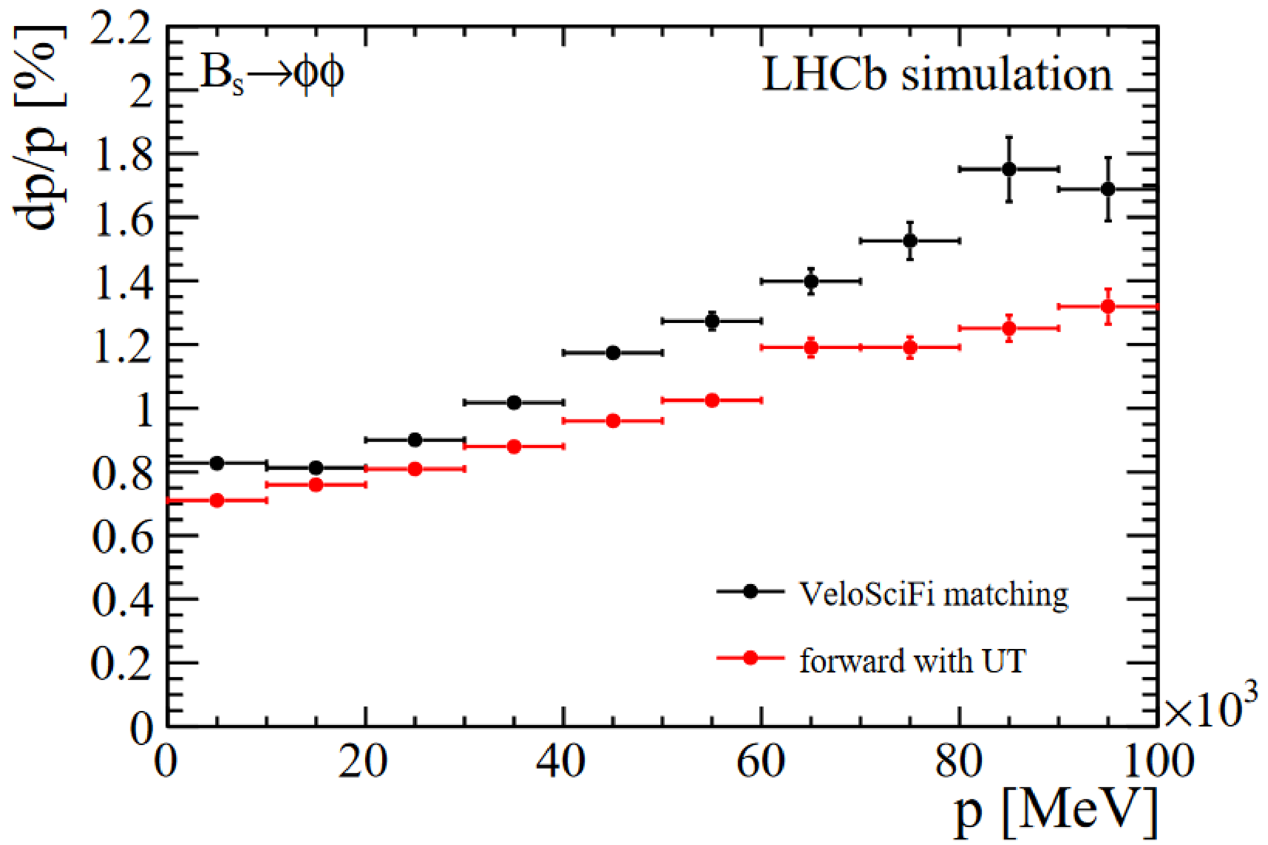
Thank you



Backup: Performance (Momentum resolution) [LHCb-FIGURE-2022-010]

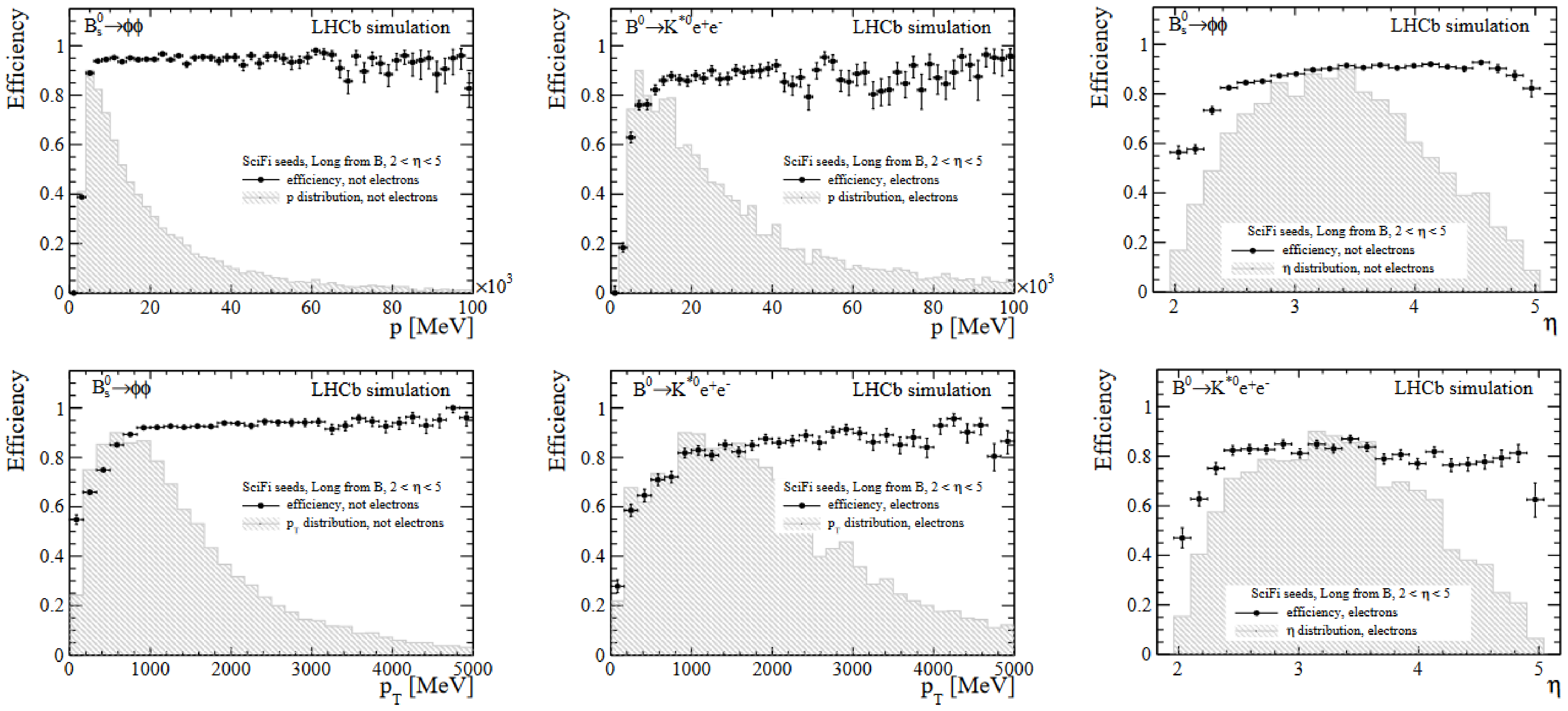


Momentum resolution for HLT1 long tracks from B decays as a function of momentum p. The plot shows reconstructed tracks from 5000 simulated B0s → ϕϕ events where the seeding + matching approach is used for the reconstruction.



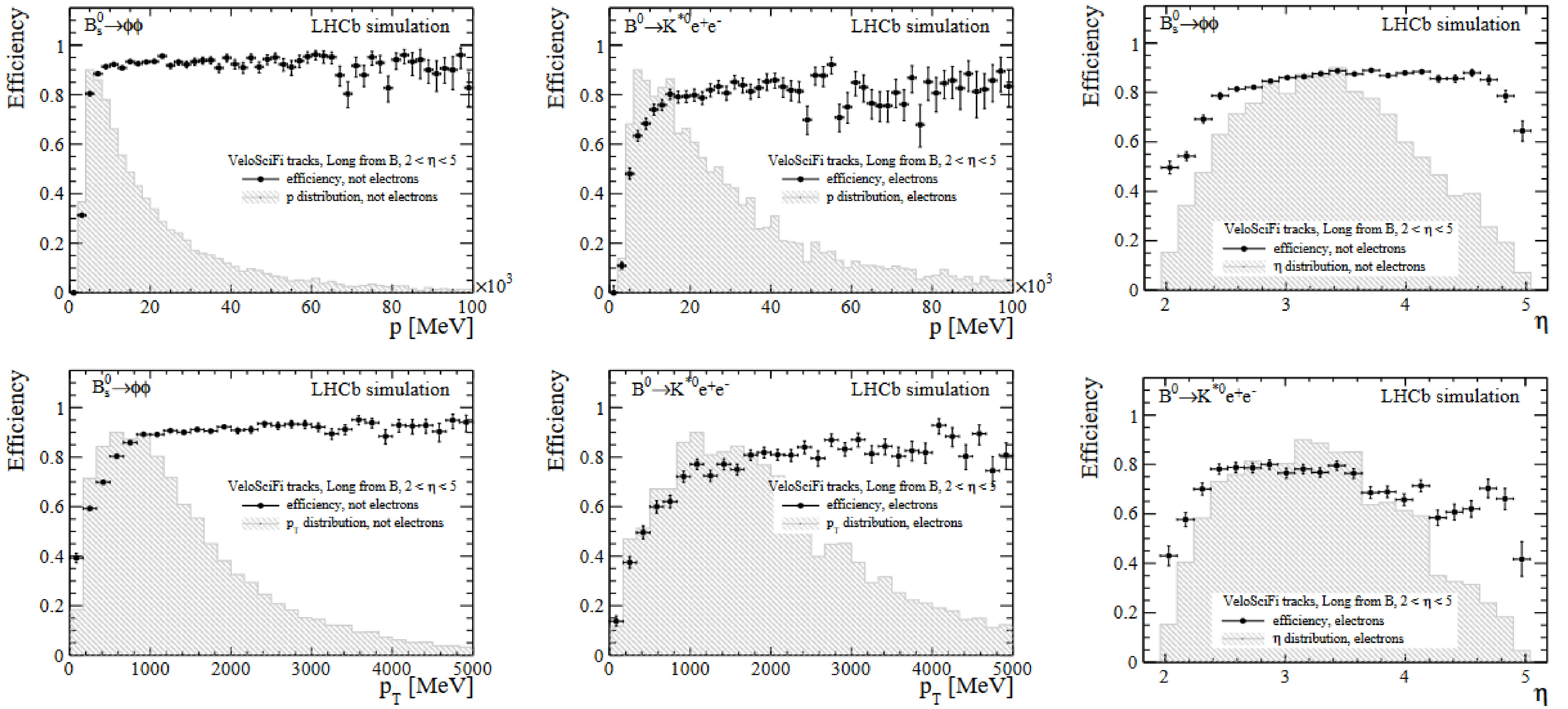
Comparison of the momentum resolution between HLT1 long tracks from the HSM (without UT) (black) and the forward tracking (with UT) (red) from B decays as function of momentum p. The plots are showing reconstructed tracks from 5000 simulated B0s → ϕϕ events. Here the main difference in the high-p region is mainly due to the HSM algorithms running without UT which is the scenario for the data taking in the first year of Run 3

Backup: Performance (Efficiencies SciFi seeds) [LHCb-FIGURE-2022-010]



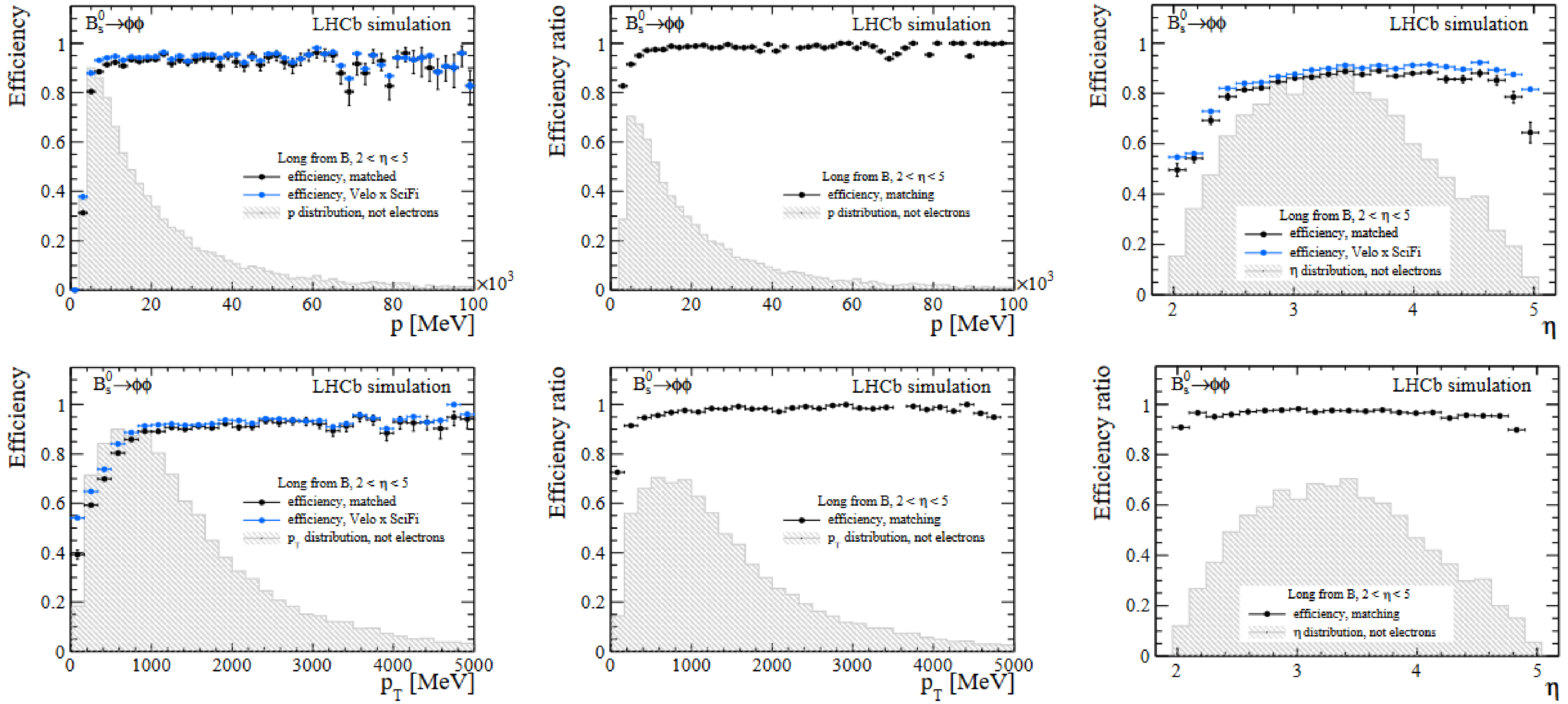
Tracking efficiencies for HLT1 SciFi seeds from B decays as function of momentum p and transverse momentum pT and pseudo-rapidity η. The plots are showing reconstructed SciFi seeds from 5000 simulated B0

Backup: Performance (Efficiencies Scifi + Velo matching) [LHCb-FIGURE-2022-010]

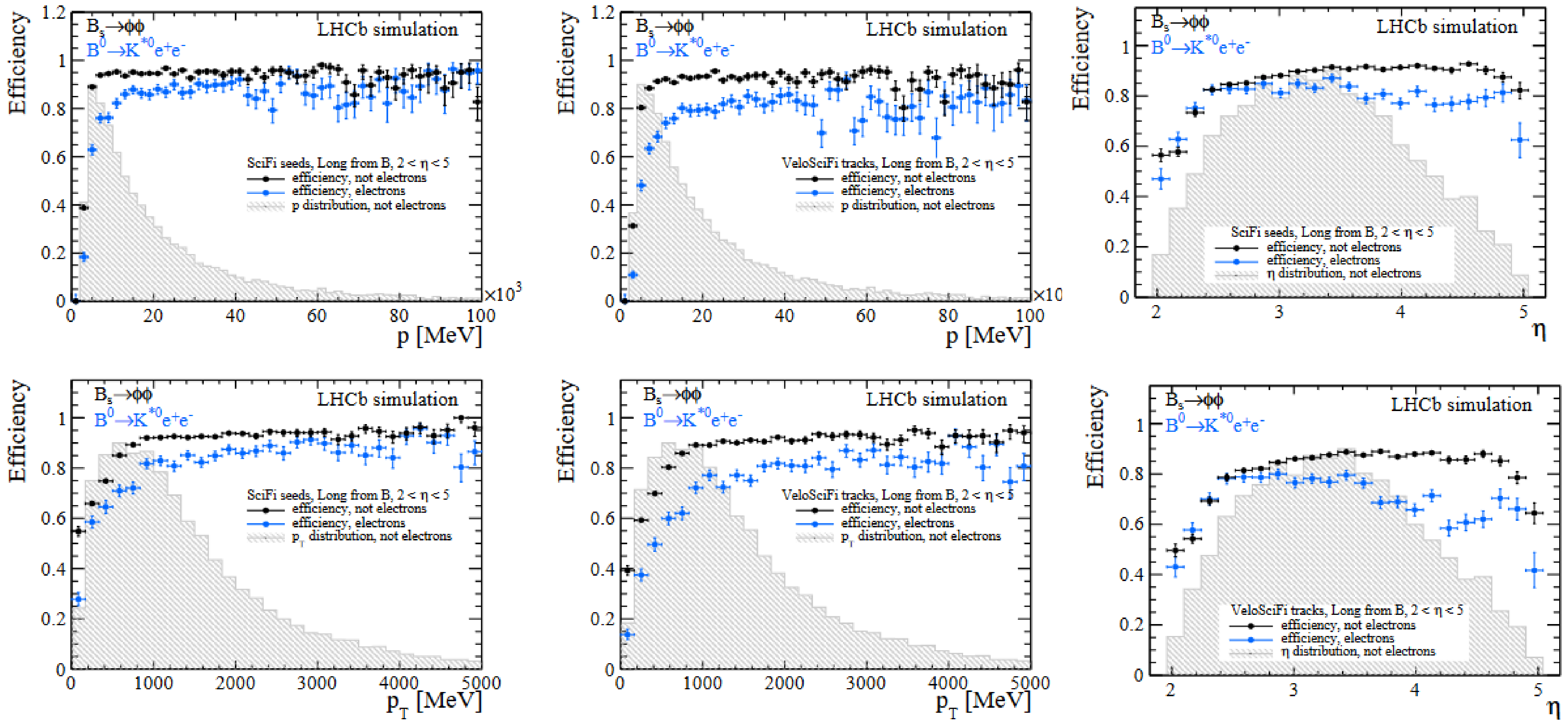


Tracking efficiencies for HLT1 long tracks from B decays as function of momentum p and transverse momentum pT and pseudo-rapidity η. The plots are showing reconstructed tracks from 5000 simulated B0 events where the seeding + matching approach is used for the reconstruction.

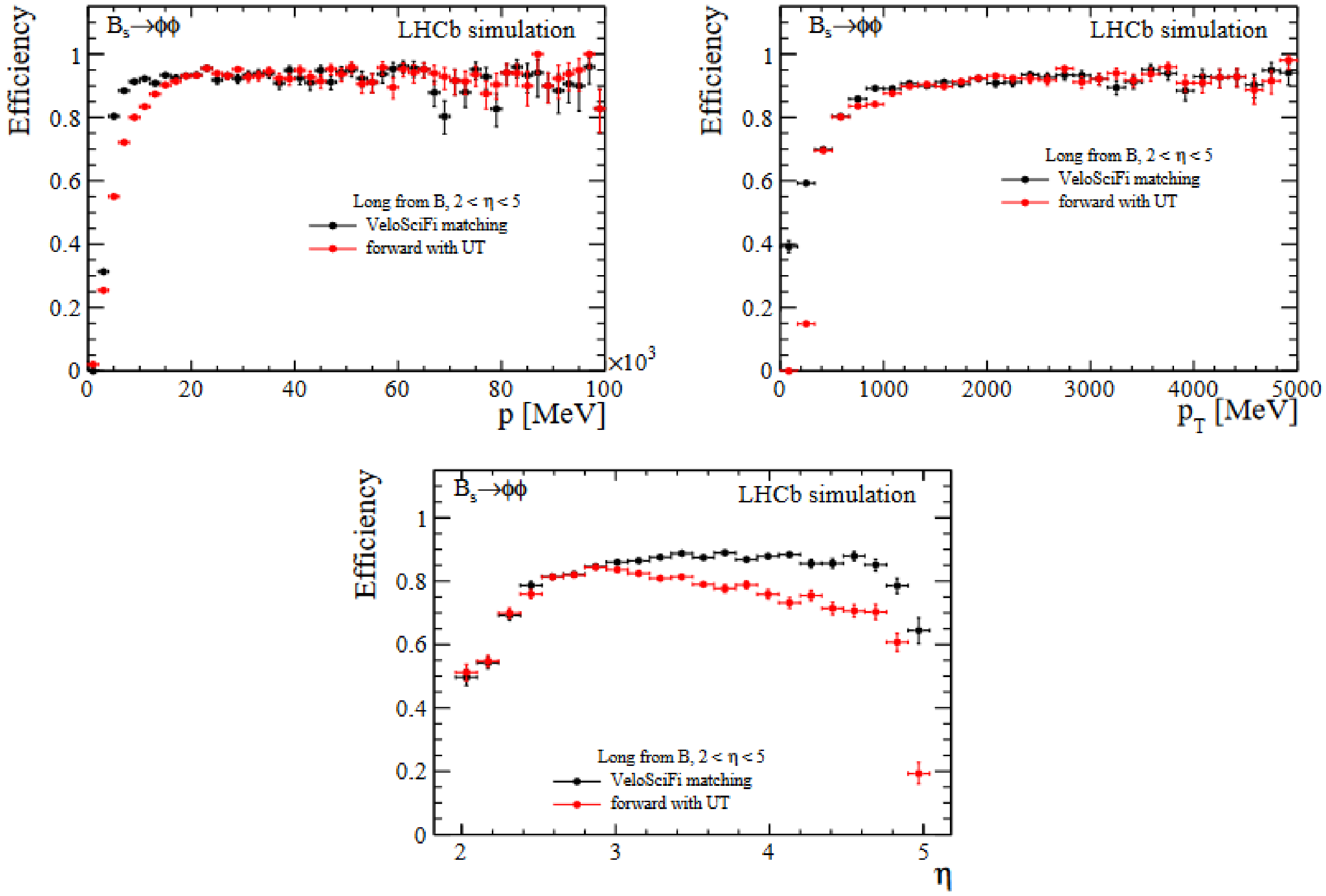
Backup: Performance (Efficiencies comparision of SciFi x Velo vs Matching) [LHCb-FIGURE-2022-010]



Comparison of the tracking efficiency for HLT1 long tracks from B decays with the product of the tracking efficiencies from VELO tracks and SciFi seeds (left) as function of momentum p and transverse momentum pT and pseudo-rapidity η as well as their ratios which is corresponding to the efficiency of the matching (right). The plots are showing reconstructed tracks from 5000 simulated B0s → ϕϕ events where the VELO tracking, SciFi seeding and seeding + matching approach are used for the reconstruction



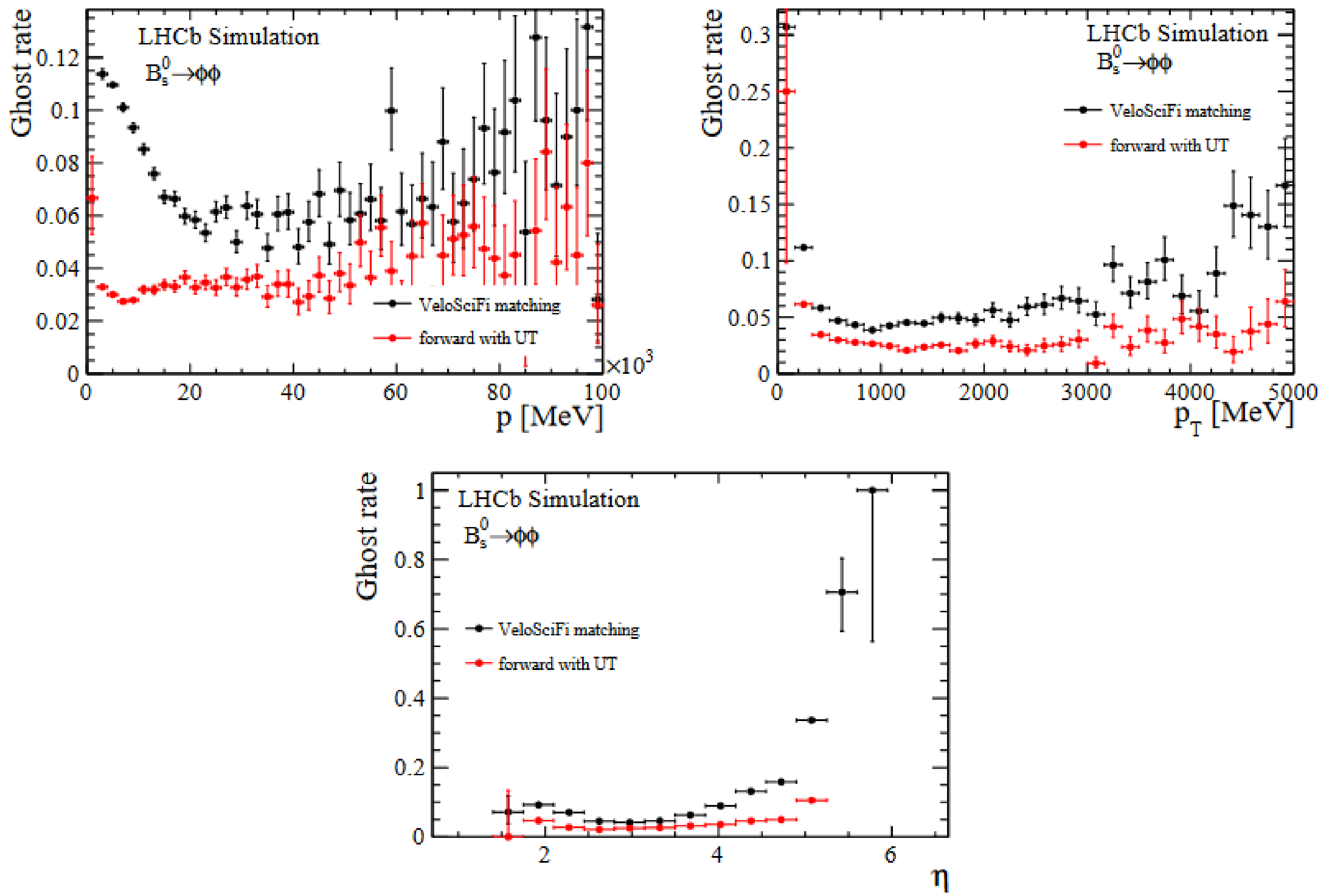
Tracking efficiencies for HLT1 electron (blue) and non-electron (black) SciFi seeds (left) and VeloSciFi tracks (right) from B decays as function of momentum p, transverse momentum pT and pseudo-rapidity η. The plots are showing reconstructed tracks from 5000 simulated B0s → ϕϕ (black) and B0 → K∗0e+e− (blue)



Comparison of the tracking efficiencies between HLT1 long tracks from the Velo-SciFi matching (black) and the forward tracking with UT (red) from B decays as function of momentum p and transverse momentum pT and pseudo-rapidity η. The plots are showing reconstructed tracks from 5000 simulated B0s → ϕϕ events.

Backup: Performance (Ghost rates comparison of long tracks from forward vs Scifi+Velo matching)

[LHCb-FIGURE-2022-010]



Comparison of the ghost rates between HLT1 long tracks from the Velo-SciFi matching (black) and the forward tracking with UT (red) from B decays as function of momentum p and transverse momentum pT and pseudorapidity η. The plots are showing reconstructed tracks from 5000 simulated B0s → ϕϕ events.