# Standalone track reconstruction in LHCb's SciFi detector for the GPU-based High Level Trigger

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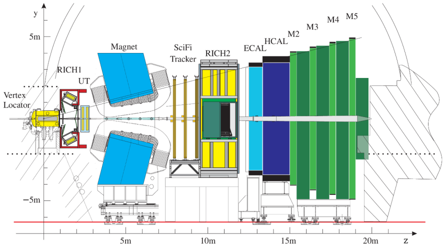
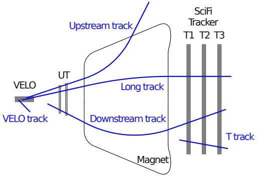
# Track reconstruction in LHCb

- LHCb's tracking sub-detectors: Velo, UT, SciFi
- UT not available during the commissioning
- Use Velo and SciFi to reconstruct Long tracks
- This talk focuses on the SciFi tracker $\Rightarrow$ 3 stations, 2 vertical "X layers" and 2 tilted "U/V layers" each, divided into 2 parts ($y > 0/y < 0$)



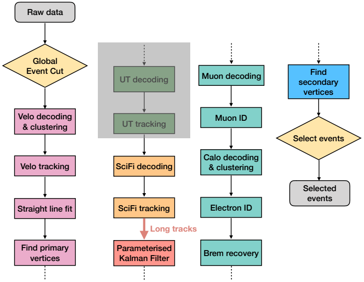



# High Level Trigger on GPUs

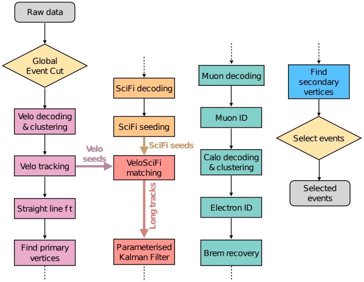
For Run 3, LHCb uses a 2 stages software HLT:

- HLT1 takes event at 30MHz and runs on O(200) GPUs
- HLT2 takes HLT1-filtered events at 1MHz and runs on CPUs

Default HLT1 sequence vs our proposed HLT1 sequence:




forward with UT (default)




seeding and matching (ours)

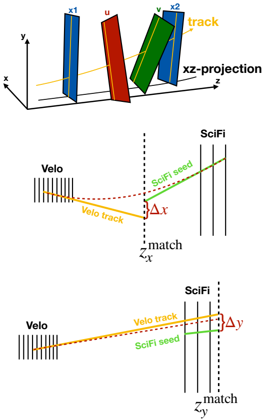
# SciFi seeding and matching

SciFi seeding:

- seed_xz: find xz-projections using only x layers
- seed_confirmTracks: augment the projections with a y component using information from tilted u/v layers

Matching:

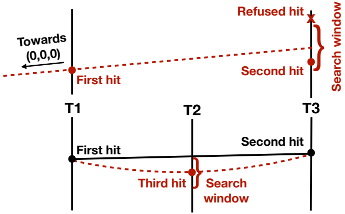
- extrapolate velo and scifi segments to a parametrized position
- measure the error and keep the best matches



# Seeding algorithm: seed_xz

For each part ($y > 0/y < 0$) independently:

- Store hits of the 6 X layers into shared memory
- Make triplets of aligned hits pointing roughly to coordinate (0,0,0)
  $\Rightarrow$ search windows in each layer are momentum dependent

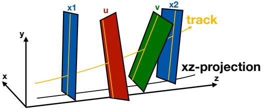


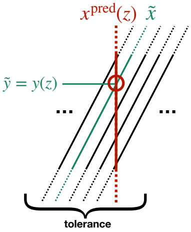

- Make 4-6 hits candidates with remaining x layers in registers
- Fit track parameters in xz (3rd order polynomial) and compute $\chi^2$
- Remove duplicates

# Seeding algorithm: seed_confirmTracks

For each part ($y > 0 / y < 0$) independently:

- Store hits of the 6 U/V layers into shared memory
- Collect hits in UV layers for each xz track in parallel, starting in 2 different layers, then using the track and first hit to collect the rest
- Fit track parameters in yz (linear) and compute $\chi^2$, on the fly



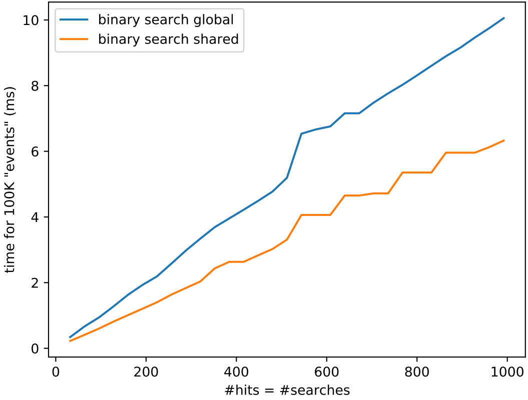
# Storing hits in Shared Memory

The seeding includes a lot of combinatorics over the hits: they are read multiple time each and most of the time in random order (non-coalesced).

But shared memory is a limited storage, how many hits do we need to store ?

- We only care about the x of the hit (4 bytes)
- We only need 6 layers and one part at a time (X layers or UV layers)
- We authorized $6 \times 300 = 1800$ hits in total: about 7.2KB
- Fallback to global memory if overflow: occurs very rarely.

# Searching hits: global or shared memory ?




Constant speedup: $\times 1.57$ when using shared memory

# Registers

Intermediate track candidates stay on the chip $\Rightarrow$ stored in registers (the fastest kind of memory on the GPU)

There are a few rules to allow the compiler to place a variable into registers (otherwise they are placed in global memory):

- Loop sizes must be known at compile time (to allow full unrolling)
- Array indices must be known at compile time
- The maximum number of registers depends on how many threads per block and how many block per streaming multiprocessor (max 64k 32-bit registers per SM)
- Delay conditional index increments to the very end of the kernel

# Registers (Loop unrolling)

```
float x, tx; // registers
float dz[6]; // registers ?
float x_pred[6]; // registers ?
for (int i=3 ; i<6 ; i++) {
    x_pred[i-3] = x + tx * dz[i];
}

// Compiler will unroll everything:
register x_pred_0 = x + tx * dz_3;
register x_pred_1 = x + tx * dz_4;
register x_pred_2 = x + tx * dz_5;
```

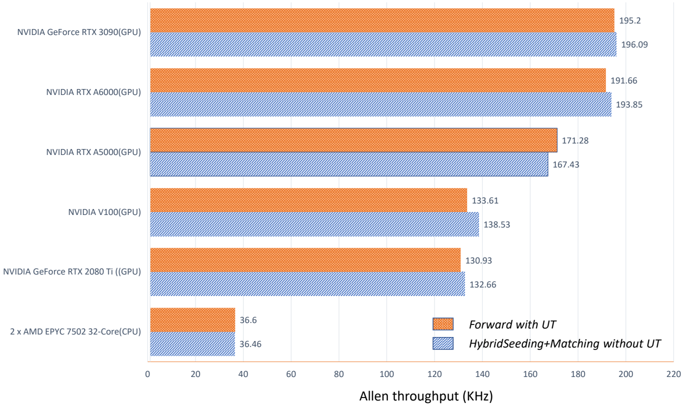
# Registers (early conditional increment)

```
int hits[6]; // local variable
int nHits = 0;
for (int i=0 ; i<6 ; i++) {
  // idx from somewhere, conditional increments:
  if (idx != -1) hits[nHits++] = idx;
}
// ...
for (int i=0 ; i<nHits ; i++) {
  tracks[threadIdx.x].idx[i] = hits[i];
}
// Gets translated to:
ld.global.u32 %r2, [%rd2];
setp.eq.s32 %p1, %r2, -1;
@%p1 bra $L__BB0_2;
st.local.u32 [%rd1], %r2;
// ...
ld.local.u32 %r42, [%rd38]; // load from local (global) memory
st.global.u32 [%rd39], %r42; // store in global memory
```

# Registers (delayed conditional increment)

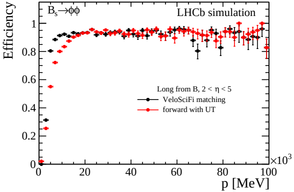
```
int hits[6]; // local variable
int nHits = 0;
for (int i=0 ; i<6 ; i++) {
  hits[i] = idx; // always store (idx may be invalid)
}
// ...
for (int i=0 ; i<6 ; i++) {
  if (hits[i] != -1) tracks[threadIdx.x].idx[nHits++] = hits[i];
}
// Gets translated to:
ld.global.u32 %r1, [%rd6];
ld.global.u32 %r2, [%rd6+4];
ld.global.u32 %r3, [%rd6+8];
ld.global.u32 %r4, [%rd6+12];
ld.global.u32 %r5, [%rd6+16];
ld.global.u32 %r6, [%rd6+20];
// ...
setp.eq.s32 %p1, %r1, -1;
@%p1 bra $L__BB1_2;
st.global.u32 [%rd9], %r1; // store register in global memory
```

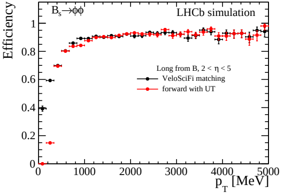
# Comparison to forward tracking with UT

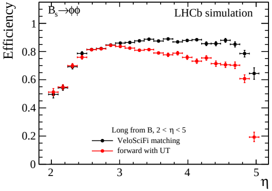



The currently installed ∼200 RTX A5000 can handle the full detector input at 30MHz

# Comparison to forward tracking with UT

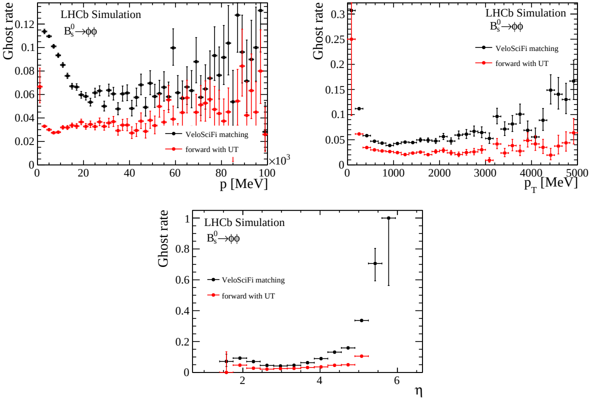



Matching is more efficient at low p / pt and at high eta, since no explicit momentum cuts are needed to meet throughput requirements.

# Comparison to forward tracking with UT




Matching has more ghosts due to the absence of UT informations. Ghosts could be killed when UT becomes available.

# Conclusion

We developed a standalone algorithm to reconstruct tracks in the SciFi detector:

- fast enough to run in real-time on GPUs
- provides an alternative way of reconstructing long tracks in abscence of UT
- as efficient as the standard forward tracking with UT
- opens possibilities to reconstruct downstream tracks when UT become available

Our algorithm is currently being used in the commissioning of the detector and the software trigger.

A standalone UT seeding and downstream matching is in development.