Many-cores studies on pattern recognition in the LHCb experiment

S. Gallorini
on behalf of the GPU@LHCbTrigger team
University of Padova & INFN
TIPP2014 - Amsterdam - June 5th 2014

Introduction

- The use of commercial General Purpose Graphic Processing Units (GPGPUs) and other many-core architectures (MIC, ...) opens up possibilities for **new complex triggers**
- GPGPUs can be used to process many events in parallel for real-time selection, and may offer a solution for reducing the cost of the High Level Trigger (HLT) farm
- Track finding algorithms are usually well suited for parallelization
- ALICE already integrated GPU gaming cards for tracking in the HLT ("Cellular Automaton" algorithm) [IEEE Transactions On Nuclear Science, 58, 4, 2011]

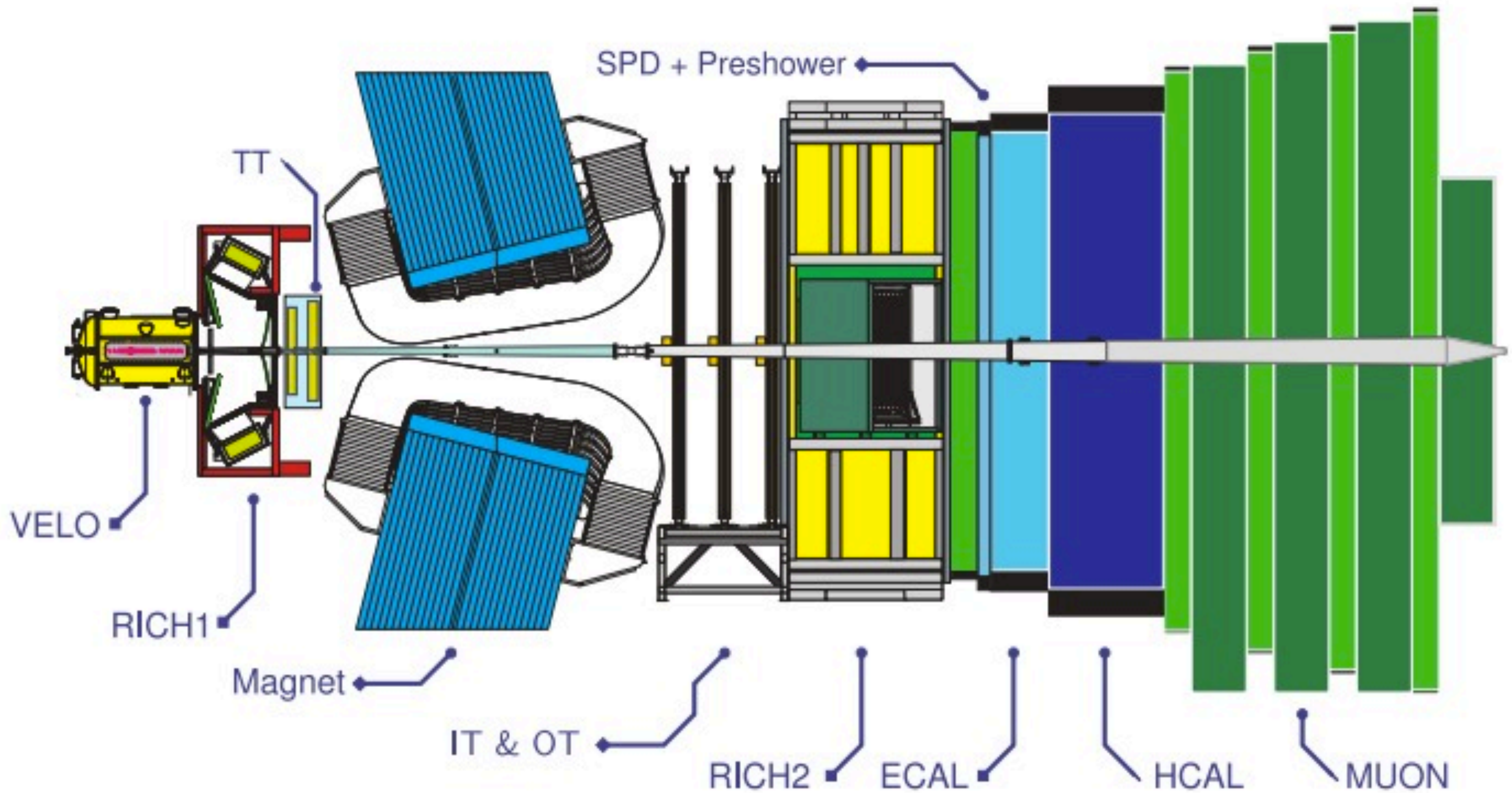
Many-core in LHCb

- In LHCb we have a small event size (O(100 kB)) and a relatively short processing time
  - ➡ A huge speed-up could be obtained by processing **many events in parallel**

- Several activities started in LHCb aiming to use many-core architectures in the HLT (tracking, vertex finding and RICH reconstruction).

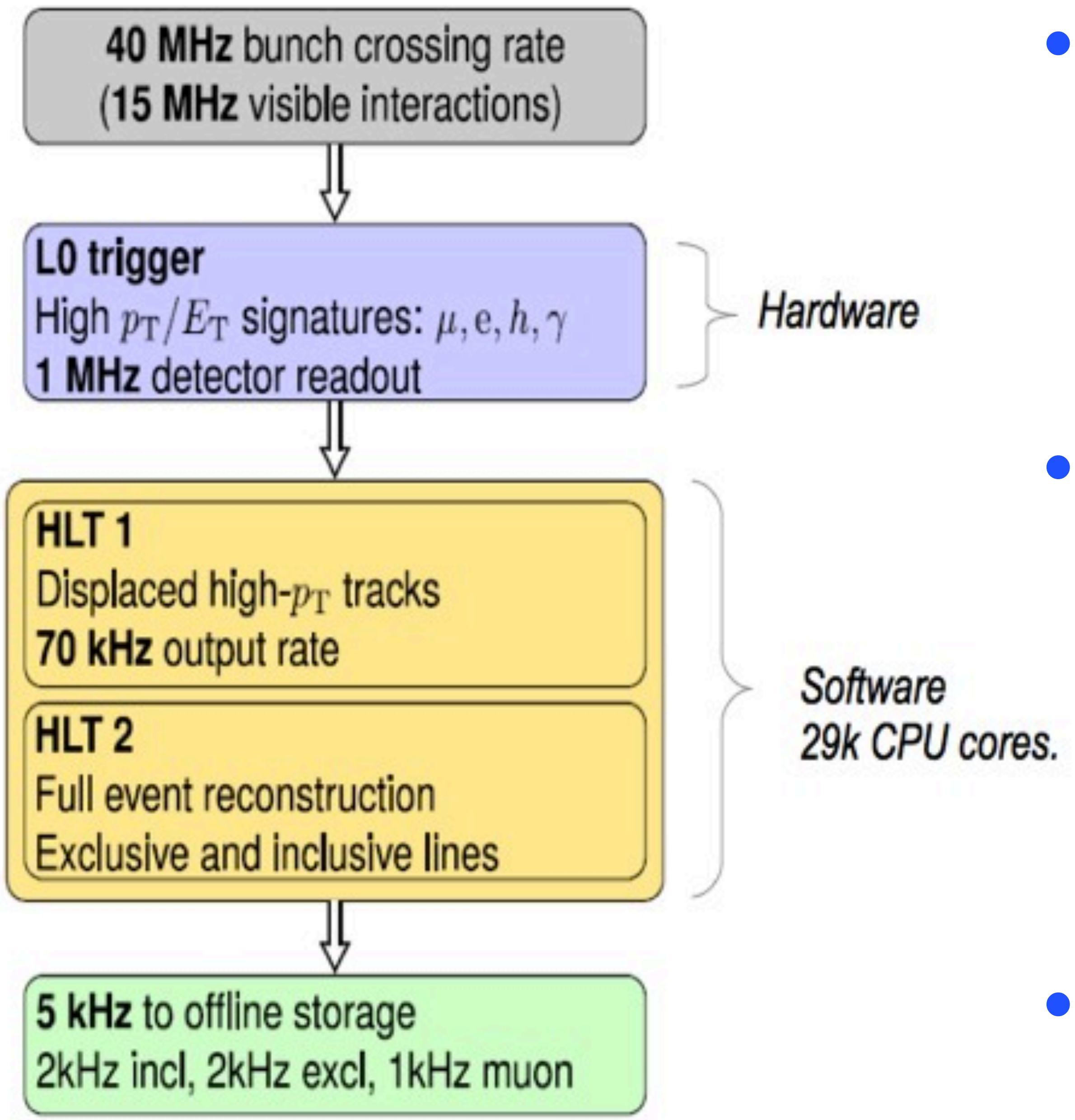
- In this talk, I will focus on the study of tracking algorithms on GPU for the VErtex LOcator detector (VELO)

The LHCb detector



- LHCb is a single-arm forward spectrometer at the LHC aiming at precision beauty and charm physics:
    - CP violation, rare decays, heavy flavour production
- An highly efficient trigger is required for selecting pure data samples for rare decays

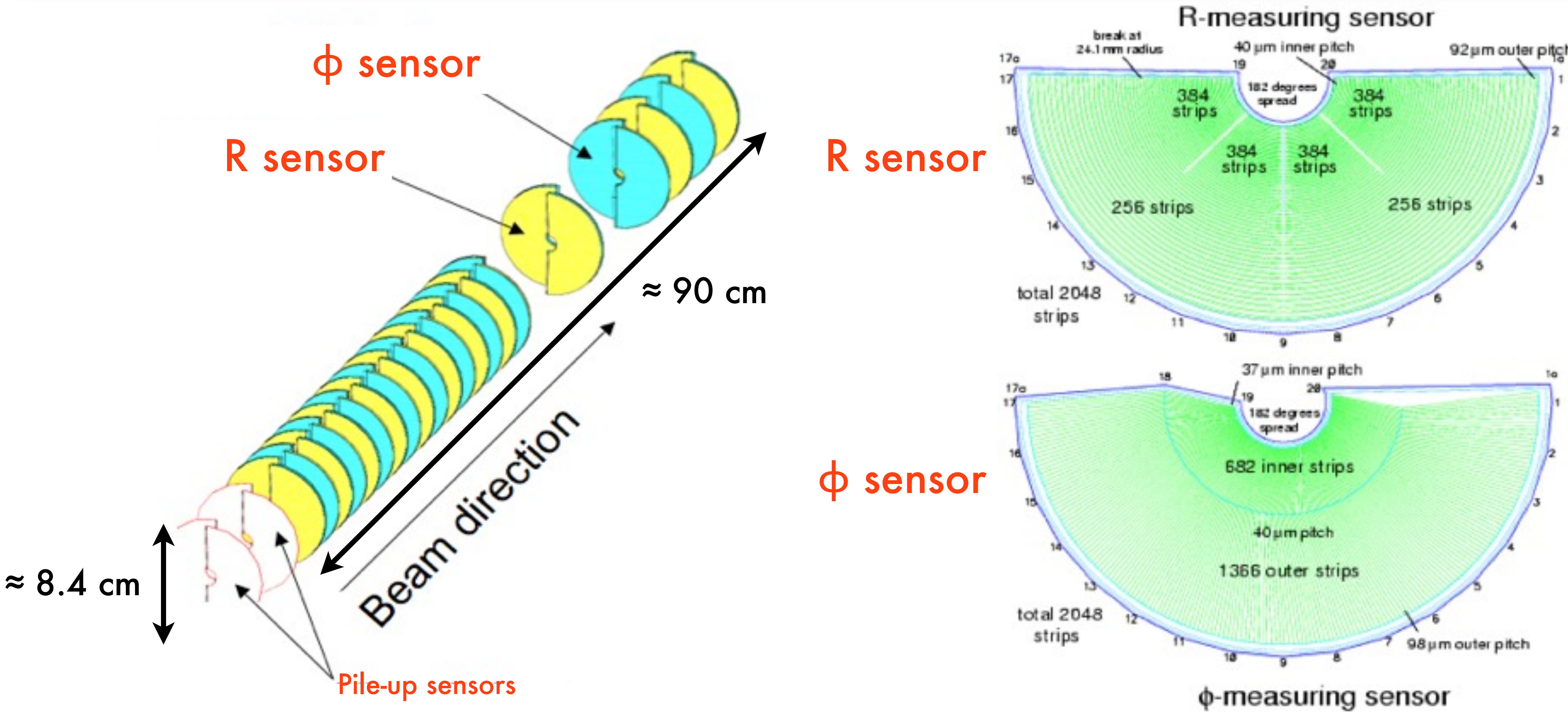
The LHCb trigger system



- **L0** reduces the rate to below 1.1 MHz:
  - Input from the calorimeter and muon systems
  - Read-out decision in 4μs
- **HLT1** reconstructs:
  - Tracks in the vertex detector (VELO)
  - Primary vertices
  - Forward tracks to tracking detectors downstream the magnet
- **HLT2** fully reconstructs the event:
  - Performance close to offline reconstruction

- The available resources in the Event Filter Farm limited the time per event in the HLT to ≈30 ms

The VELO detector



- The VELO detector is a silicon micro-strip detector situated close to the interaction region
- R-ϕ layout, 21 stations with 2R and 2ϕ sensors each (+ 4 pile-up sensors)
- It provides precise and fast tracking information which was employed in the HLT during Run I (2011-2012)

VELO pattern recognition

- "FastVelo" is the algorithm developed by LHCb for pattern recognition in the VELO
- It ran online in the HLT farm during Run I:
  - Written to be fast and highly efficient to cope with high rate and hit occupancy
  - Several conditions and checks introduced throughout the code to speed up the execution
- The VELO track reconstruction is done in two steps:

1. **RZ tracking:** only hits on R sensors are used. Find tracks in the R-Z plane.
2. **Space tracking:** add the information of ϕ sensors to each to build the full tracks

FastVelo on GPU (1)

- The goal of this work is to evaluate the performances of FastVelo on GPU wrt the original code (**optimized** for CPU):
    - Timing and tracking efficiencies (e.g. clone and ghost rates, efficiency for long tracks)

- Focus on the current VELO tracking running in HLT1

<u>Definitions</u>:

- efficiency= $\frac{N_{reconstructed\ \&\ reconstructible\ particles\ \&\ no\ electrons}}{N_{reconstructible\ particles\ \&\ no\ electron}}$
- ghost track= reconstructed track not matched to any true particle
- clone tracks= tracks associated to the same true particle
- long track= track reconstructed in VELO and in tracking stations (“T-stations”)

FastVelo on GPU (2)

- **Strategy:**

- Parallelize on the events (obvious...)

- Parallelize the algorithm:

  - Process each RZ track concurrently:

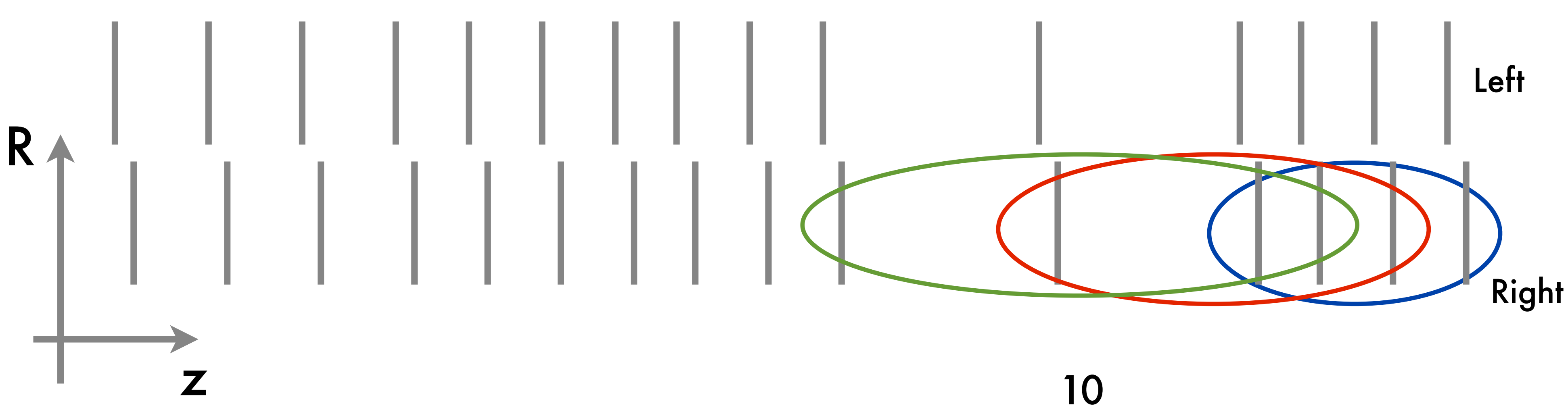
    - In the original algorithm hits already used in a track are marked and not further considered in the following iterations ("hit tagging")

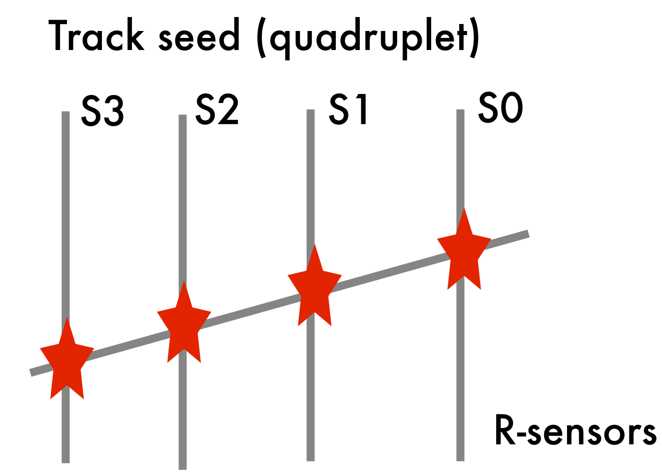
    - ... but to avoid race-conditions, **hit tagging** must be **removed** in the GPU algorithm (clones and ghosts tracks diverge!)

- For the rest... try to keep the GPU version as closest as possible to the original one (code writtten in CUDA langauge)

FastVelo on GPU (3)

- **RZ tracking:**
- Only R-sensors are used
- The algorithm looks for quadruplets of hits in four contiguous R-sensors (seed) on both halves.
  - Each thread works on a set of four contiguous R-sensors and find all quadruplets.
- Then each quadruplet is extended in parallel as much as possible adding the remaining R-sensors





FastVelo on GPU (5)

- **Space tracking:**
- Add hits on ϕ-sensors
- Each RZ track is processed concurrently by assigning a space-tracking algorithm to each thread:
  - Search for a triplet of hits: for each hit in the first two ϕ-sensors, the candidate hit in the third sensor is the one most compatible with predicted position (best χ^2)
  - The track is extended and its parameters are found by minimizing $\Sigma_{points}\,\chi^2$ (linear system solved by substitution)
  - This part is almost a re-writing in CUDA language of the original space-tracking code

FastVelo on GPU (6)

- **Main issue:**

- Without tagging on used hits, we end up with a large amount of clones and ghosts

- **Solution:**

- "Clone killer" algorithms are needed throughout the GPU code to reduce clones and the number of tracks

- All pairs of tracks are checked in parallel:
    - Each thread of the clone killer algorithm takes a track and computes the number of hits in common with the others; if two tracks have more than 70% of hits in common, the one with worst χ^2 is discarded

Performance evaluation

- GPU performances tested using an NVidia Titan (14 Streaming Multi-processors (SM), 192 CUDA cores/SM, 6GB of memory)
- CPU performances tested using a **single core** (Intel i7, 3.40 GHz) in the same PC hosting the GPU and a **multicore CPU** (Intel Xeon E5-2600, 24 cores w/ Hyper Threading)
- Used data samples:
  - $B_s \to \phi\phi$ MC events and MinBias data
  - b-inclusive MC events (simulated with 2015 data taking conditions)
- We use standard LHCb tools to get track efficiencies and resolutions
- **Tracking time** only! (data transfer **not included!**)

Results (1)

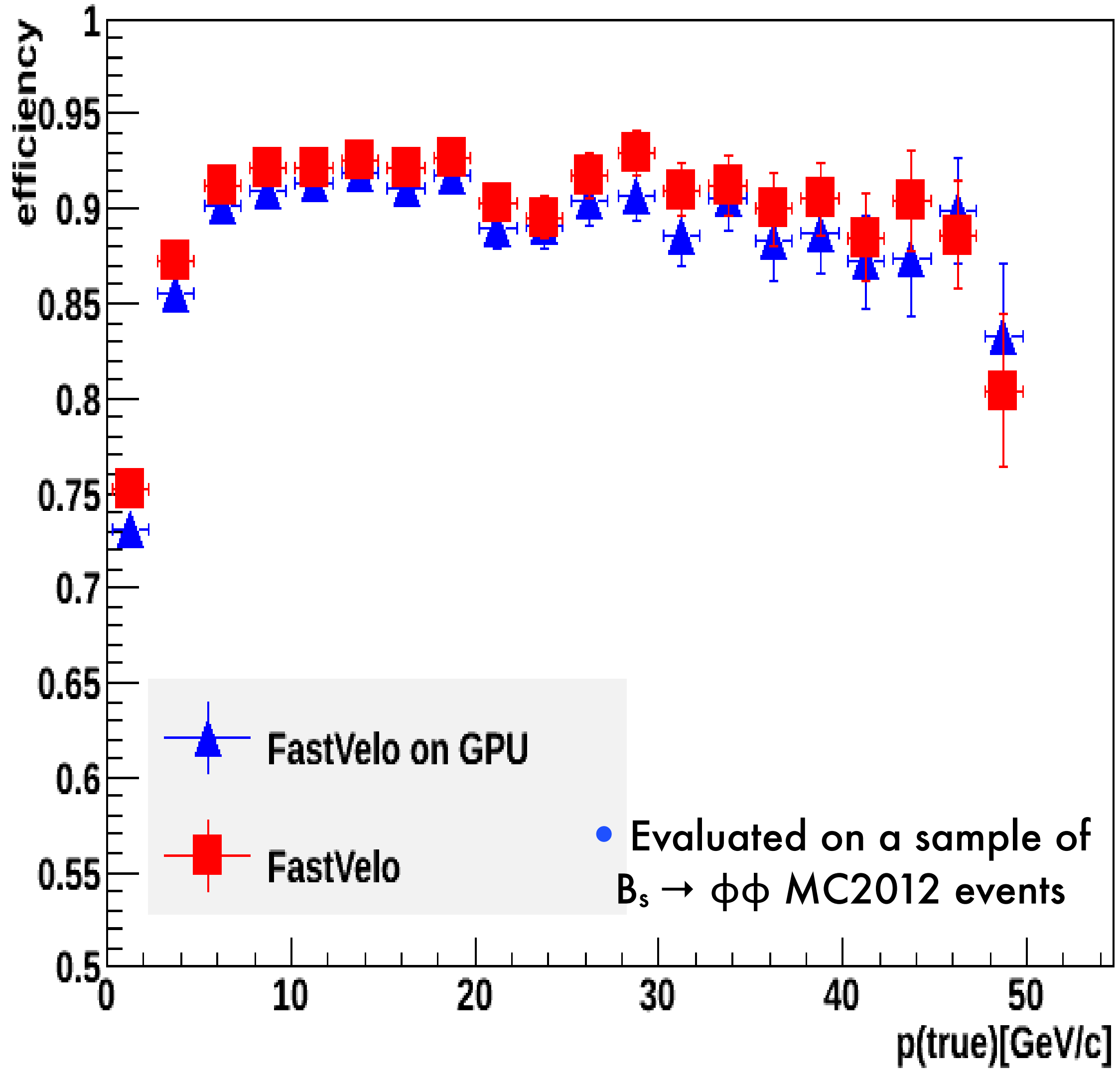
- Tracking efficiencies comparison:

- Evaluated on a sample of $B_s \rightarrow \phi\phi$ MC events

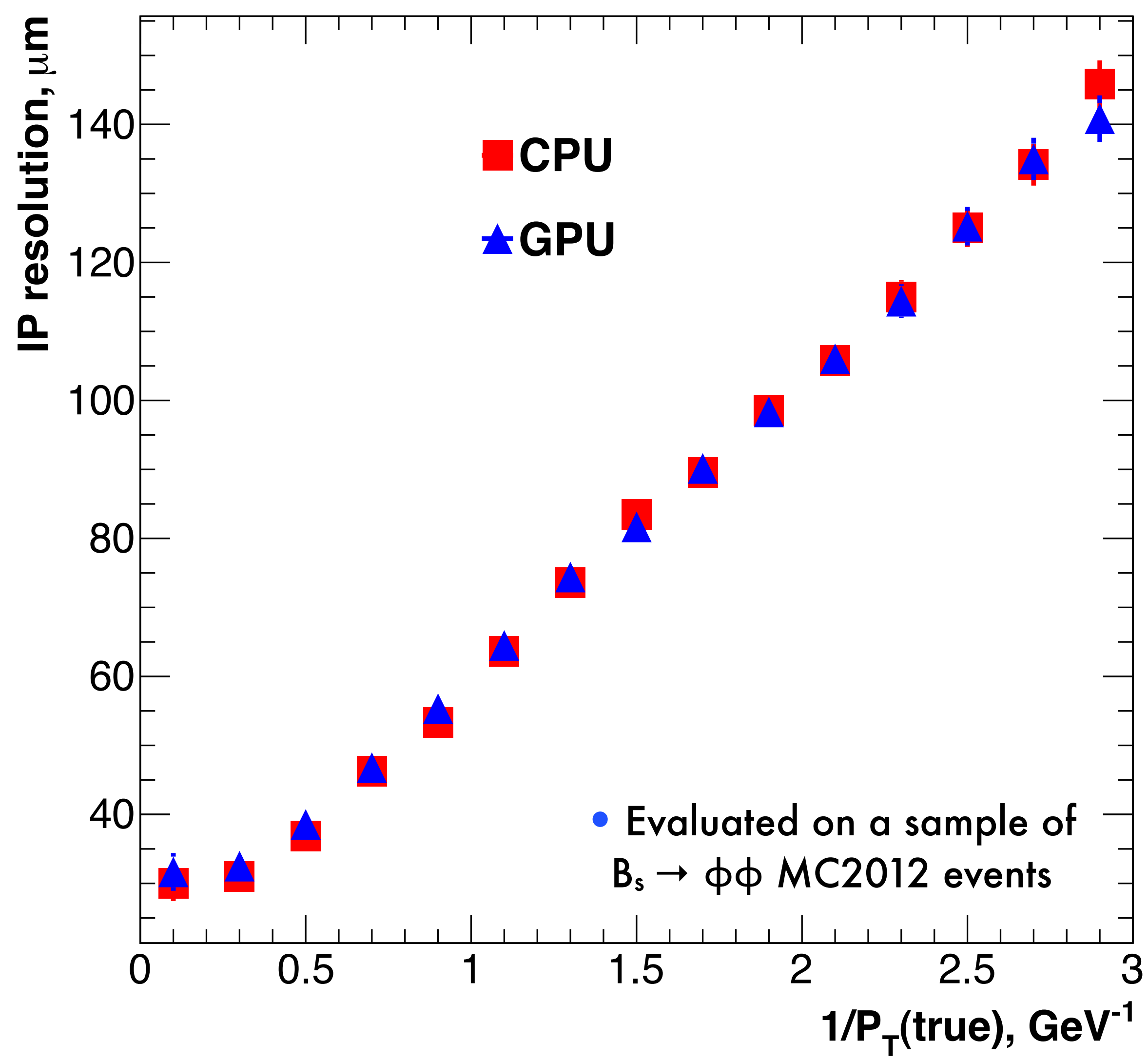
Track category	FastVelo on GPU		FastVelo on CPU	
	Efficiency	Clones	Efficiency	Clones
VELO, all long	86.6%	0.2%	88.8%	0.5%
VELO, long, p > 5 GeV	89.5%	0.1%	91.5%	0.4%
VELO, all long B daughters	87.2%	0.1%	89.4%	0.7%
VELO, long B daughters, p > 5 GeV	89.3%	0.1%	91.8%	0.6%
VELO, ghosts	7.8%		7.3%	

Results (2)

Tracking efficiency vs P(true)



Impact parameter resolution vs $1/P_T$(true)

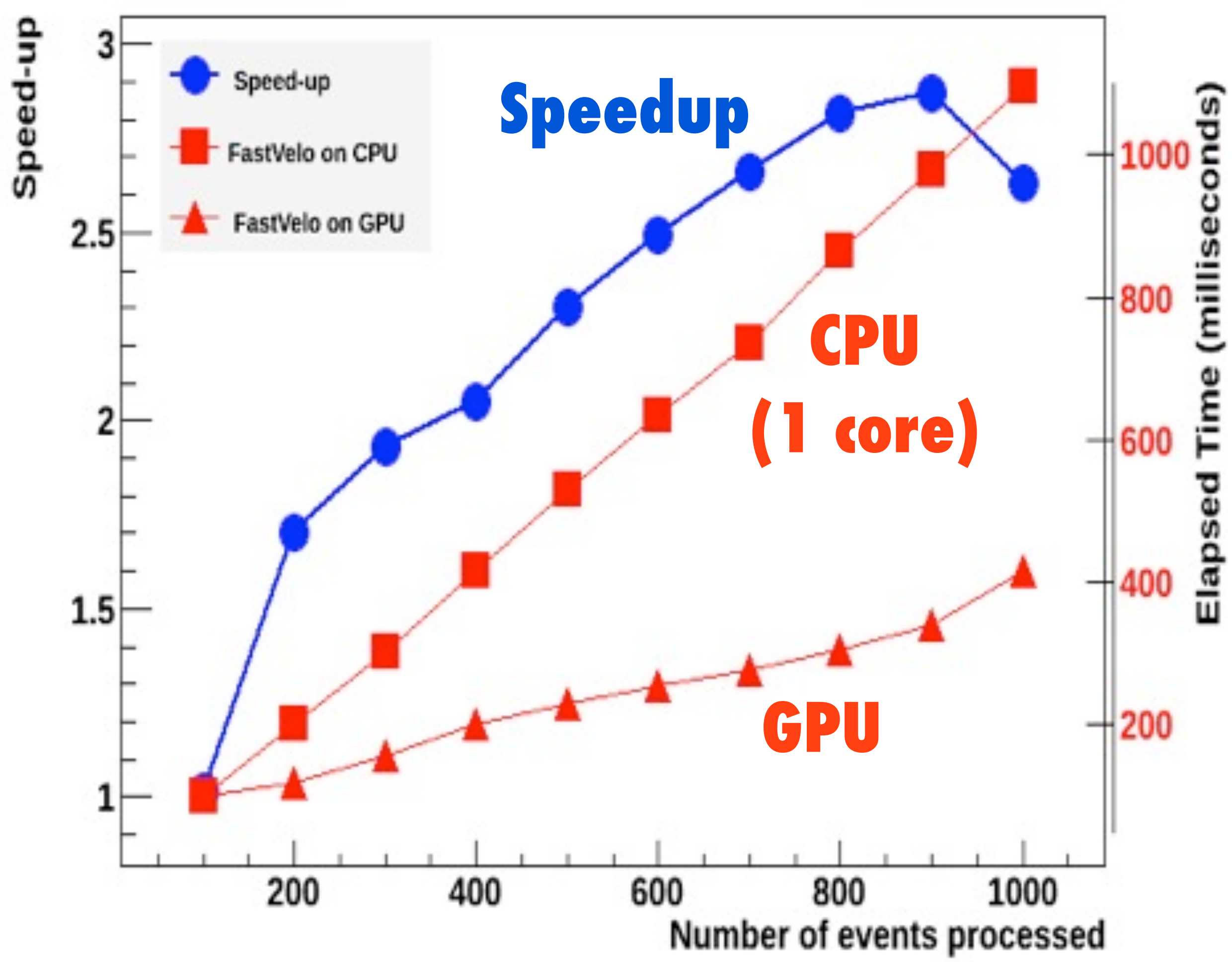


Tracking performances close to the optimized CPU code

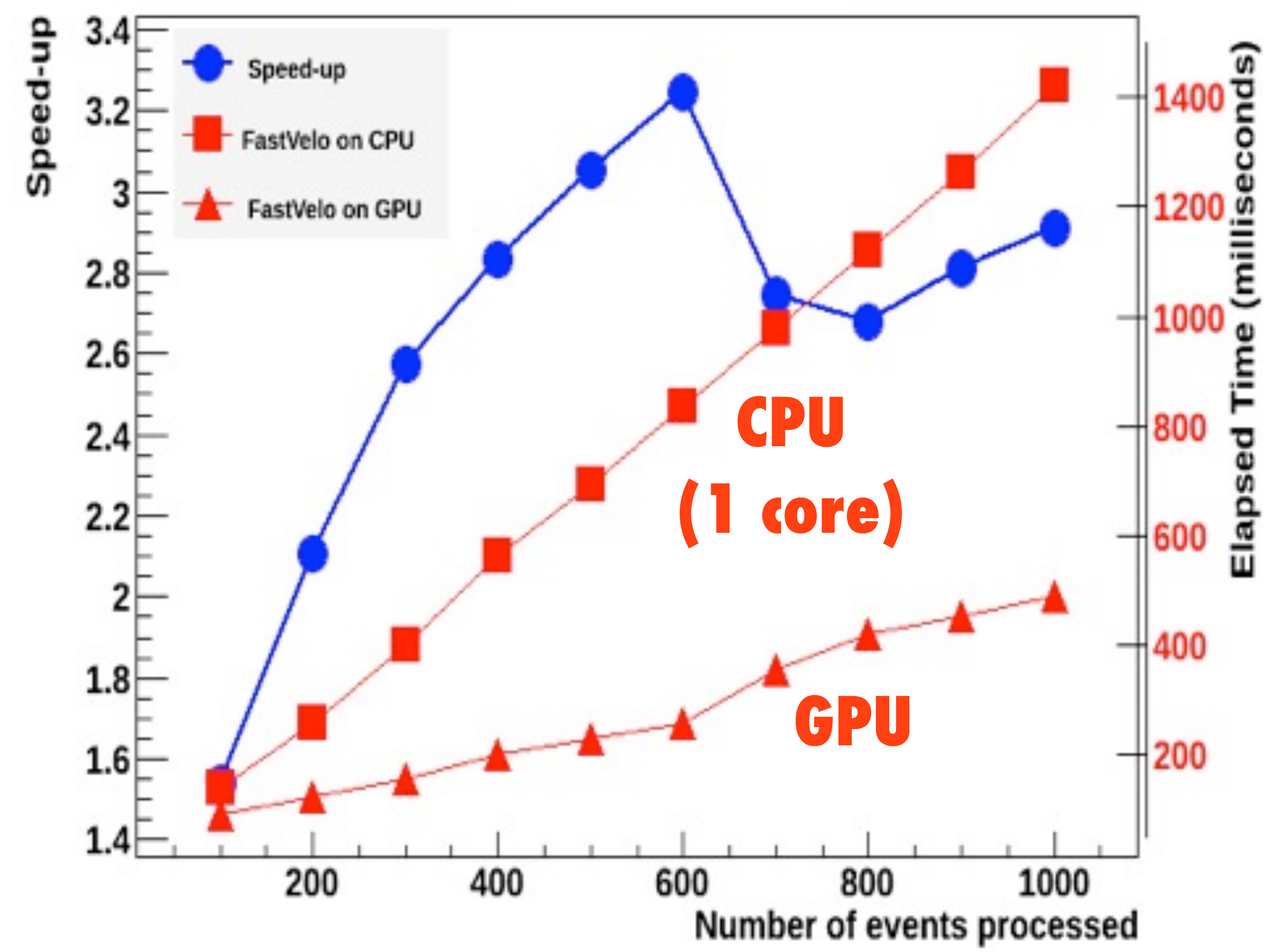
Results (3)

- Execution time as a function of the number of events

$B_s \rightarrow \phi\phi$ MC events



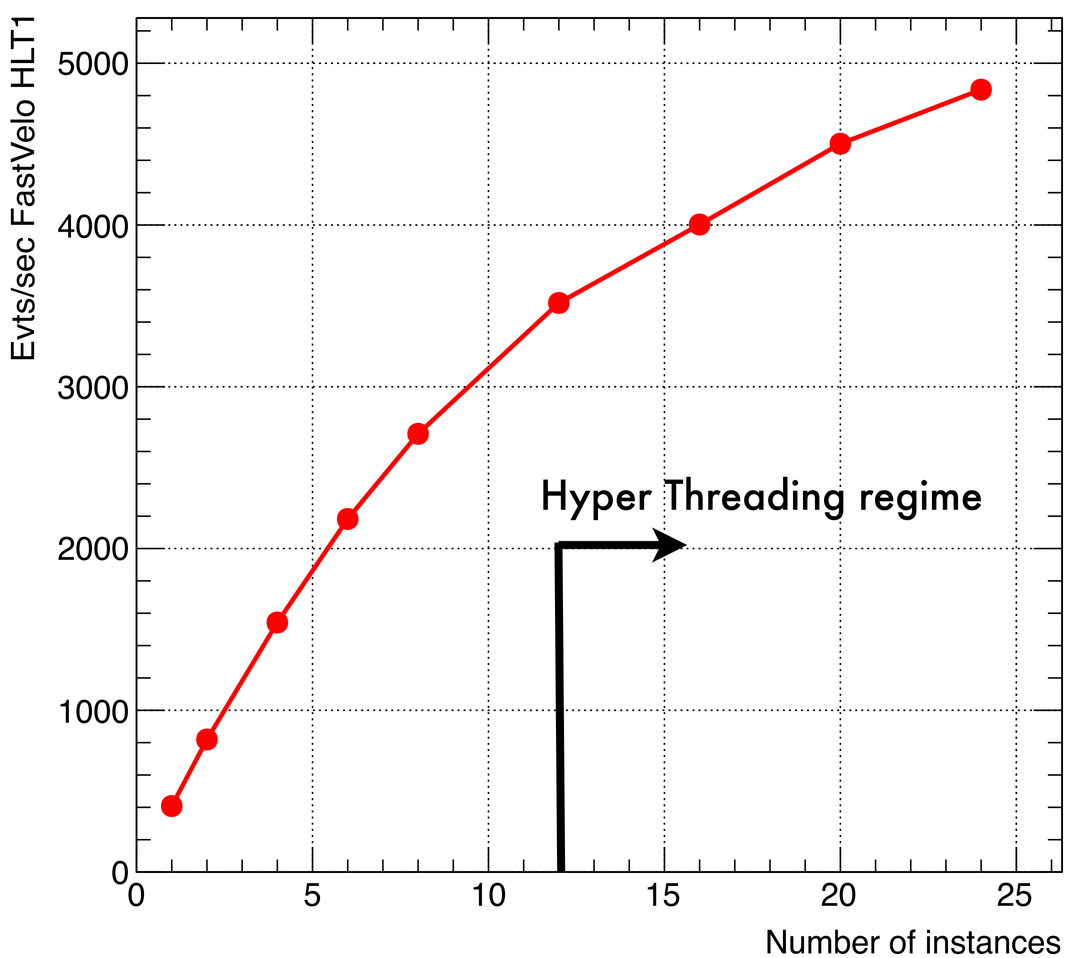
NoBias data



- GPU performances **increases** with the number of events: GPU resources are more efficiently used as the number of events increases (more threads running at the same time)

Results (5)

- GPU performances compared to a multicore CPU (24 cores w/ HT)
  - An instance of FastVelo sent to each core at the same time, with each job processing the same number of events (1000 events/job)



- The throughput of a single core decreases if more instances are running in parallel

- Rate of processed events:

≈5000 evts/sec (CPU) vs ≈2600 evts/sec (GPU)

Conclusions

- Preliminary results on VELO tracking on GPU have been shown
- Tracking performances of the GPU version close to the original CPU code
- A better performance estimator is the rate of processed events normalized to the cost of the hardware!
  - The GPU gaming-card cost less than a CPU used in a node of the HLT farm, so also a moderate speed-up (e.g. 2x) compared to e.g. Intel Xeon could bring a real saving to the experiment

Outlook

- Complete the full tracking on GPU adding hits in the tracking stations downstream the VELO
    - More time consuming than FastVelo in the HLT
- Investigate other algorithms, e.g. Cellular Automaton (seeding) + Kalman Filter (fitting).
- Test GPU tracking algorithms in a parasitic mode in the HLT during the Run II starting in 2015

Backup slides

FastVelo on GPU

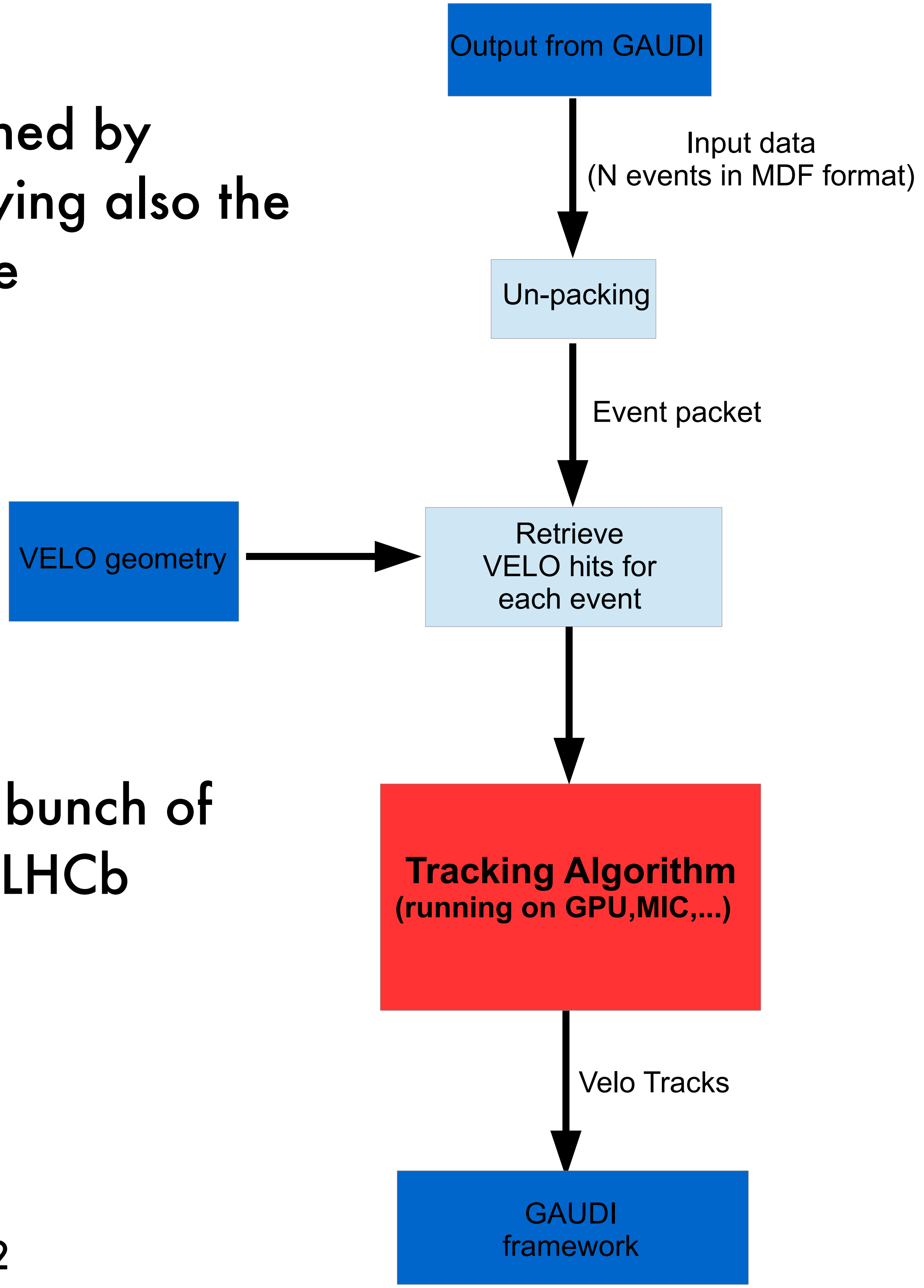
- **GPU implementation:**
  - The GPU algorithm gives priority to long tracks, using only the last five R-sensors:
    - Four threads (one per zone) find all possible quadruplets in these sensors.
    - Each quadruplet is extended independently. The hits of each RZ track are marked to avoid processing hits already used for long tracks (*)
  - Next, the remaining sensors are processed in parallel:
    - Each thread works on a set of five contiguous R-sensors and find all quadruplets. A check is done on the hits in order to avoid hits already used for the long tracks.

(*) Potential race-conditions are not an issue in this case, because the aim is to flag an hit as used for the next step of the algorithm.

Framework

- We want to explore the speed-up obtained by processing **many event in parallel**, studying also the limitations imposed by data transfer time

- Written a simple program for loading a bunch of events on the GPU decoupling from the LHCb framework ("Gaudi")



Results

b-inclusive MC events simulated with exp. 2015 conditions