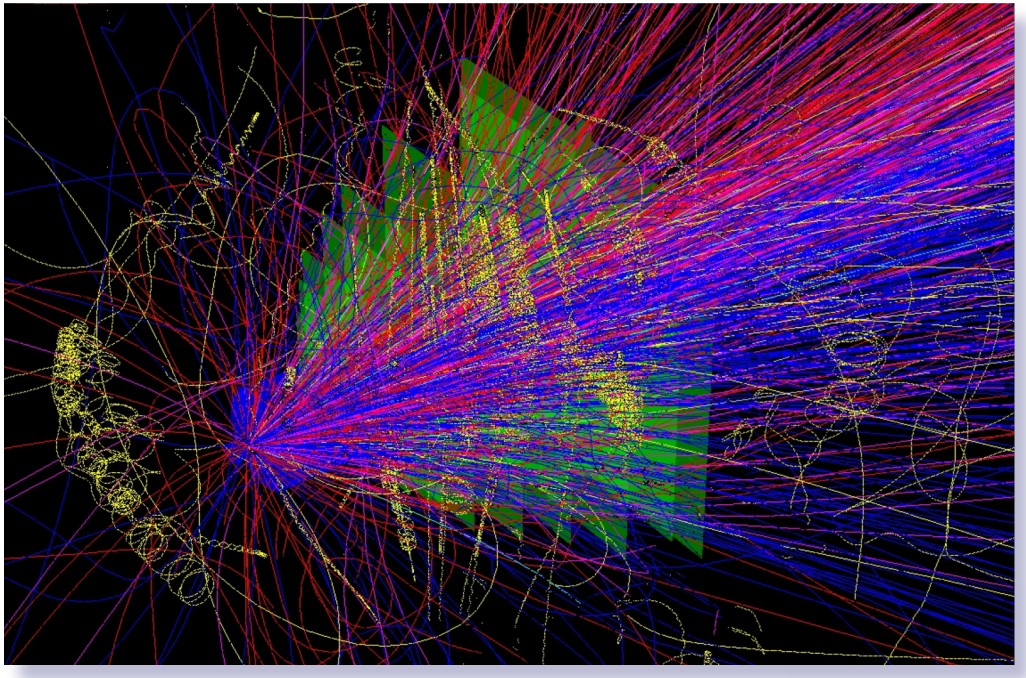
4-Dimensional Event Building in the First-Level Event Selection of the CBM Experiment

Valentina Akishina and **Ivan Kisel**
for the CBM Collaboration

Goethe-University Frankfurt am Main
FIAS Frankfurt Institute for Advanced Studies
GSI Helmholtz Center for Heavy Ion Research

Reconstruction Challenge in CBM at FAIR/GSI

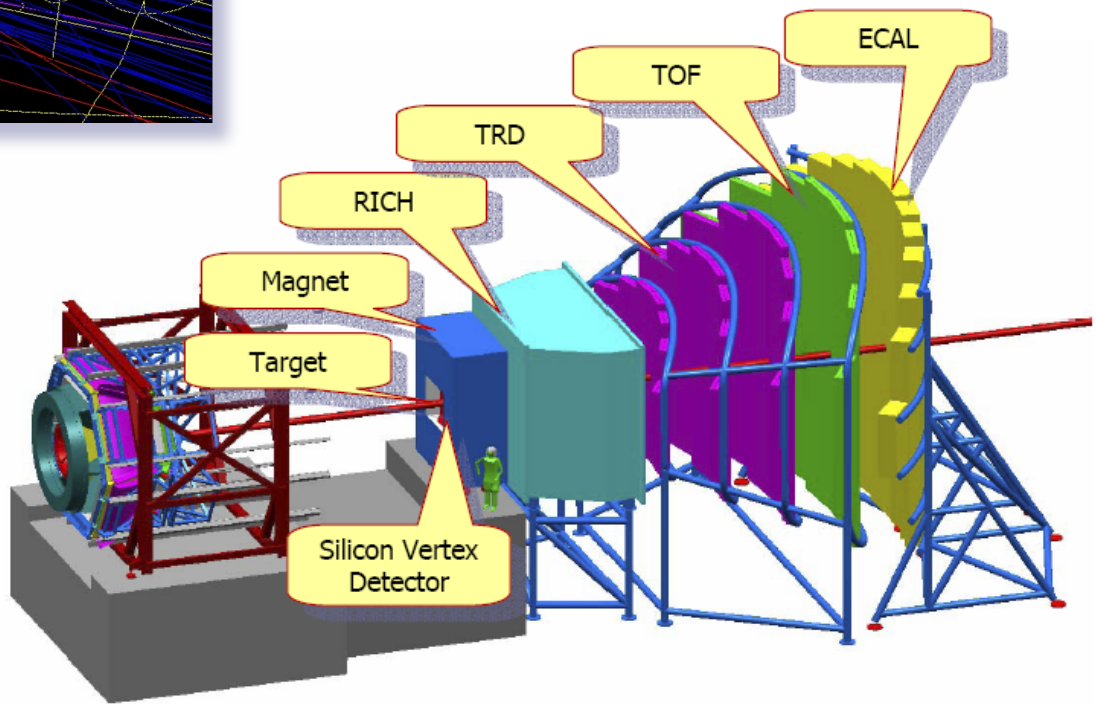


- Future fixed-target heavy-ion experiment
- 10^7 Au+Au collisions/sec
- ~ 1000 charged particles/collision
- Non-homogeneous magnetic field
- Double-sided strip detectors (85% fake space-points)

Full event reconstruction will be done
on-line at the First-Level Event Selection (FLES) and
off-line using the same FLES reconstruction package.

Cellular Automaton (CA) Track Finder
Kalman Filter (KF) Track Fitter
KF short-lived Particle Finder

All reconstruction algorithms are vectorized and parallelized.



Kalman Filter (KF) Track Fit Library

Kalman Filter Methods

Kalman Filter Tools:
- KF Track Fitter
- KF Track Smoother
- Deterministic Annealing Filter

Kalman Filter Approaches:
- Conventional DP KF
- Conventional SP KF
- Square-Root SP KF
- UD-Filter SP
- Gaussian Sum Filter

Track Propagation:
- Runge-Kutta
- Analytic Formula

Implementations

Vectorization (SIMD):
- Header Files
- Vc Vector Classes
- ArBB Array Building Blocks
- OpenCL

Parallelization (many-cores):
- Open MP
- ITBB
- ArBB
- OpenCL

Precision:
- single precision SP
- double precision DP

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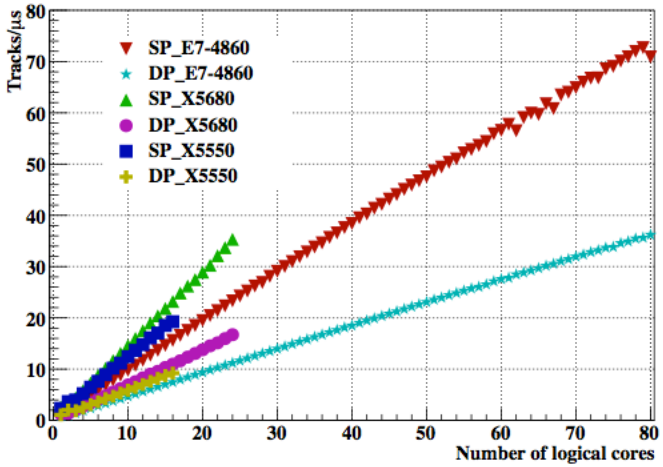
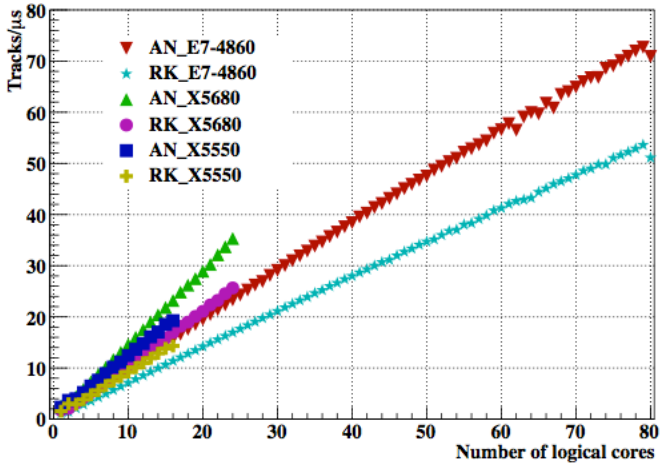
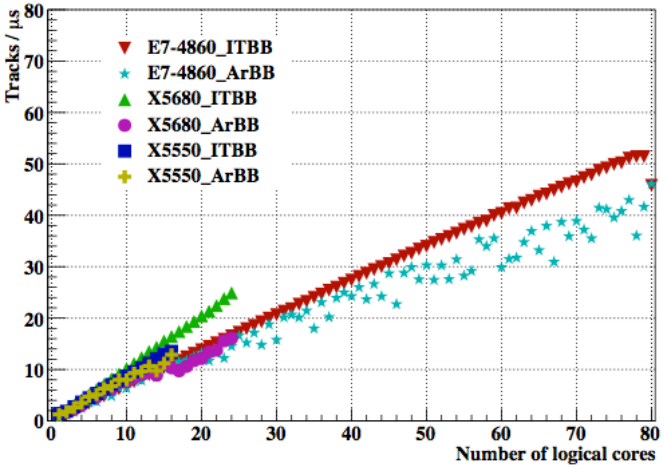
Conventional KF DP vs. SP



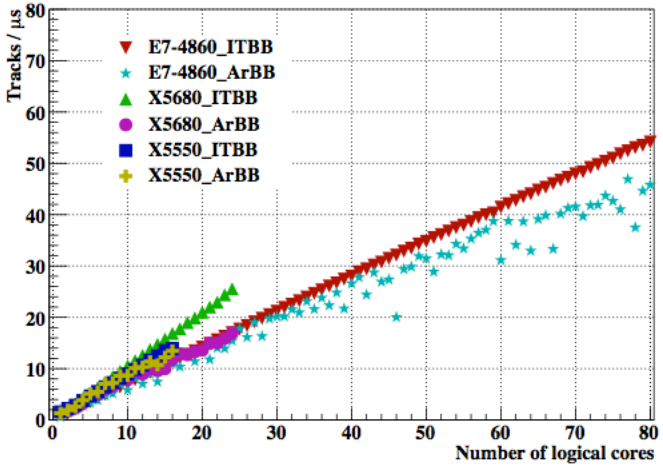
Conventional KF RK4 vs. Analytical



Square-Root KF



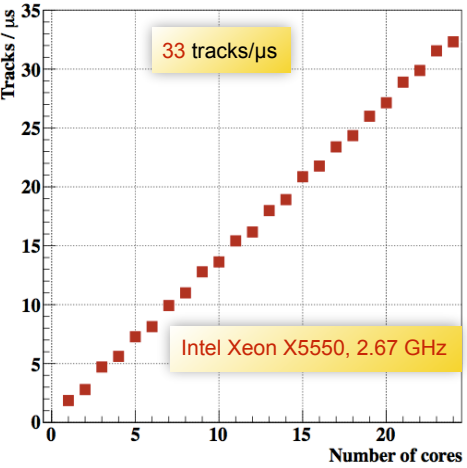
UD KF

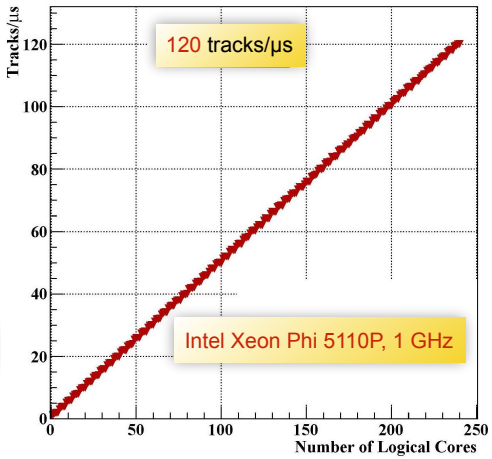


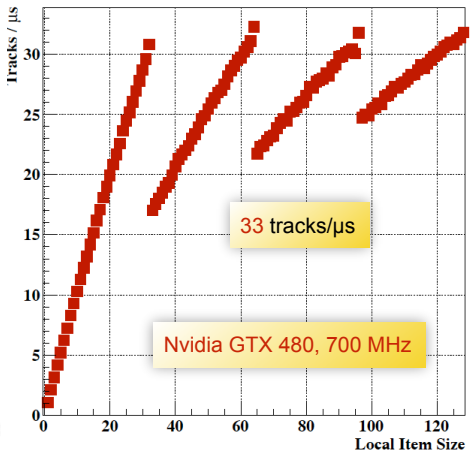
Strong many-core scalability of the Kalman filter library

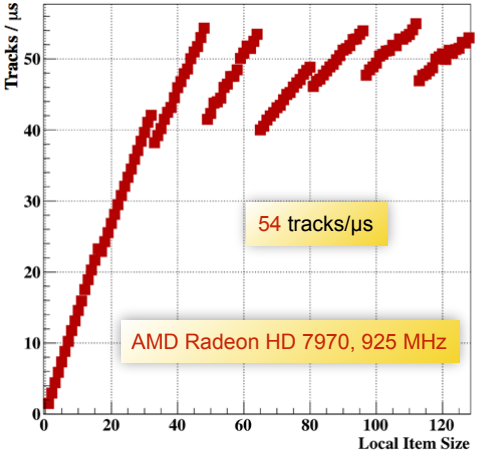
with I. Kulakov, H. Pabst* and M. Zyzak (*Intel)

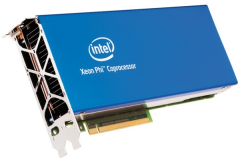
Kalman Filter (KF) Track Fit Library







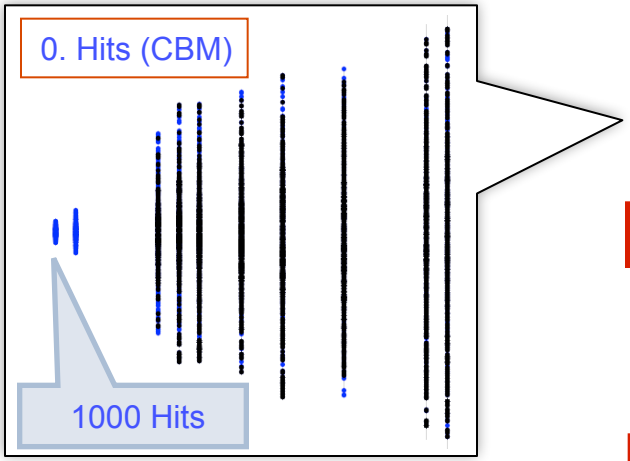


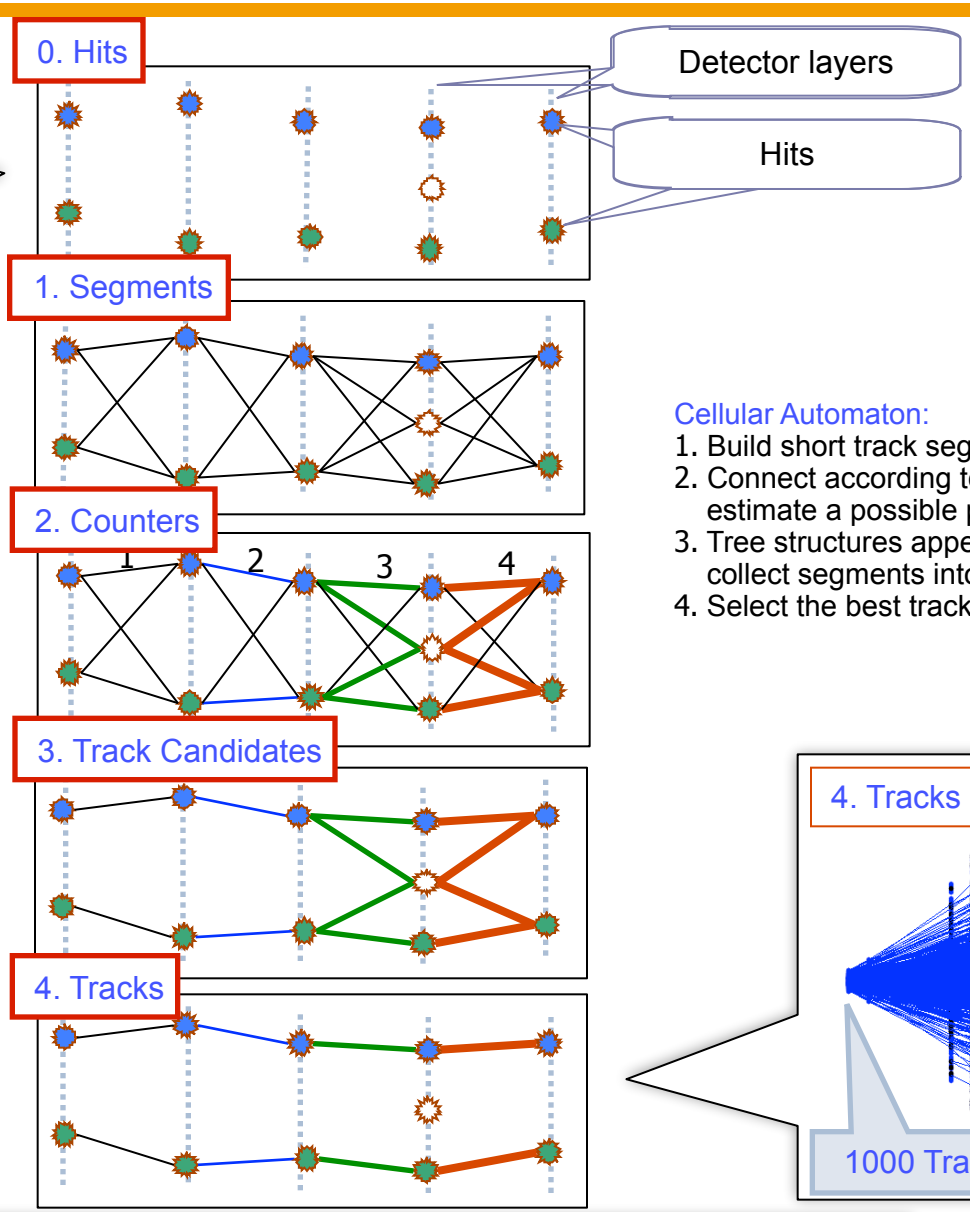


- Scalability with respect to the number of logical cores in a CPU is one of the most important parameters of the algorithm.
- The scalability on the Intel Xeon Phi coprocessor is similar to the CPU, but running four threads per core instead of two.
- In case of the graphic cards the set of tasks is divided into working groups and distributed among compute units (or streaming multiprocessors) and the load of each compute unit is of the particular importance.

Full portability of the Kalman filter library

Cellular Automaton (CA) Track Finder





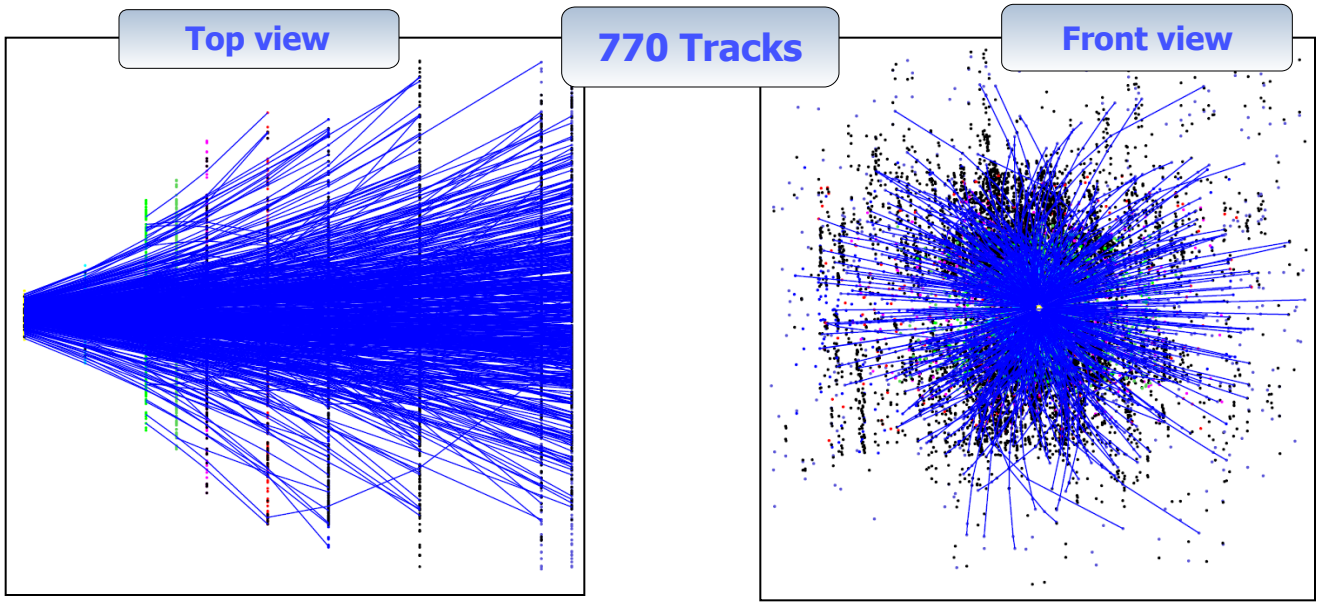
Cellular Automaton:
1. Build short track segments.
2. Connect according to the track model, estimate a possible position on a track.
3. Tree structures appear, collect segments into track candidates.
4. Select the best track candidates.

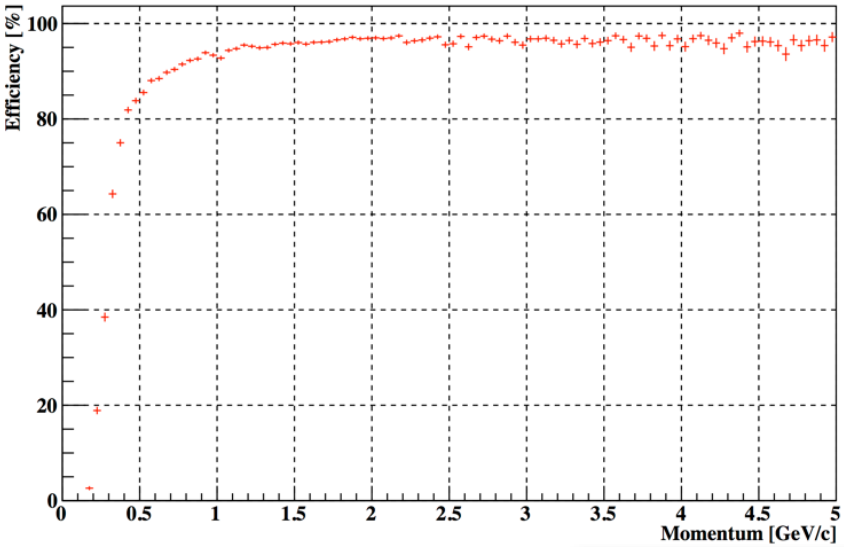
Cellular Automaton:
- local w.r.t. data
- intrinsically parallel
- extremely simple
- very fast

Perfect for many-core CPU/GPU !

Useful for complicated event topologies with large combinatorics and for parallel hardware

CA Track Finder: Efficiency



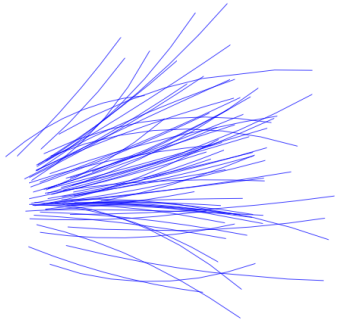


	Efficiency, %	
	mbias	central
Primary high-p tracks	97.1	96.2
Primary low-p tracks	90.4	90.7
Secondary high-p tracks	81.2	81.4
Secondary low-p tracks	51.1	50.6
All tracks	88.5	88.3
Clone level	0.2	0.2
Ghost level	0.7	1.5
Reconstructed tracks/event	120	591
Time/event/core	8.2 ms	57 ms

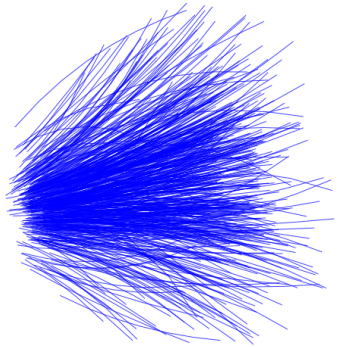
Efficient and stable event reconstruction

CA Track Finder at High Track Multiplicity

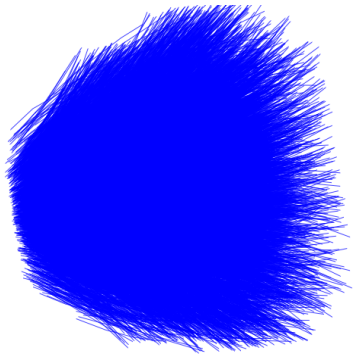
A number of minimum bias events is gathered into a group (super-event), which is then treated by the CA track finder as a single event



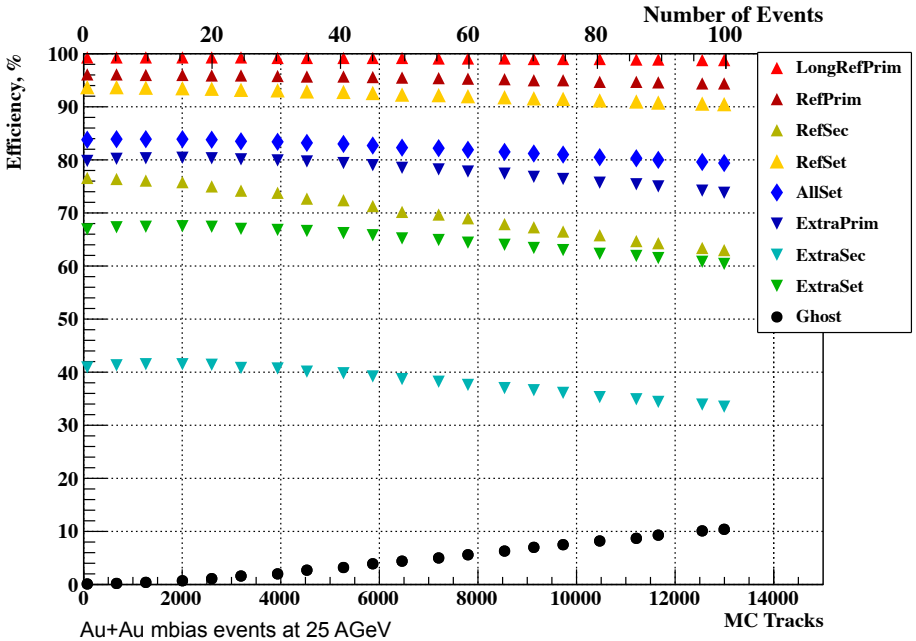
1 mbias event, <N_{reco}> = 109

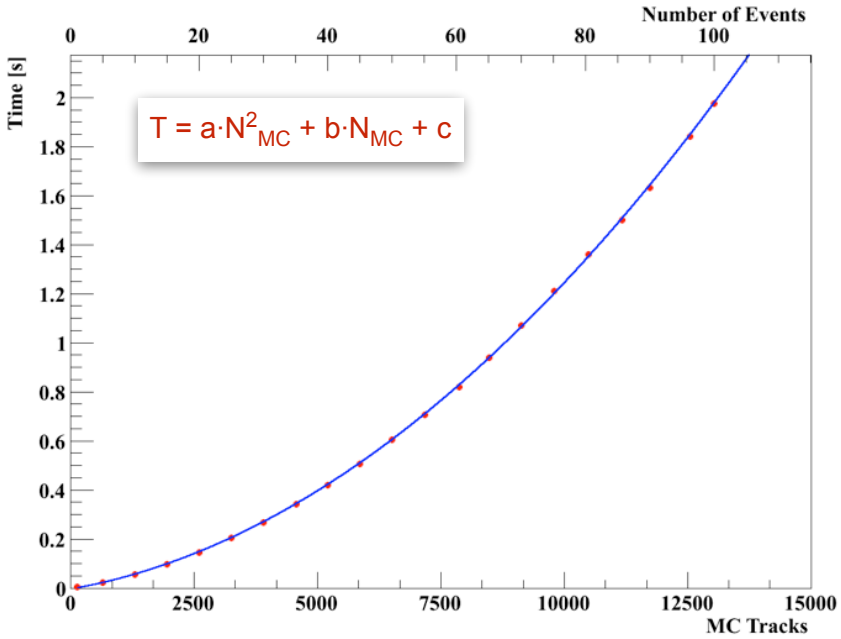


5 mbias events, <N_{reco}> = 572



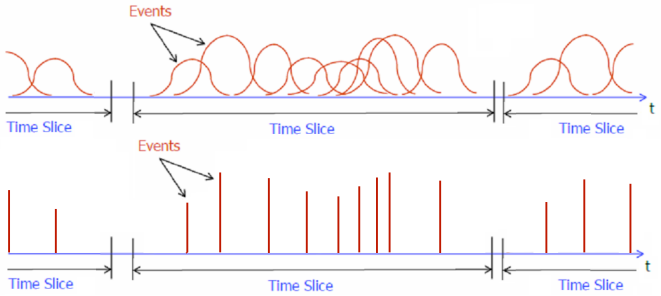
100 mbias events, <N_{reco}> = 10340





Stable reconstruction efficiency and time as a second order polynomial w.r.t. to track multiplicity

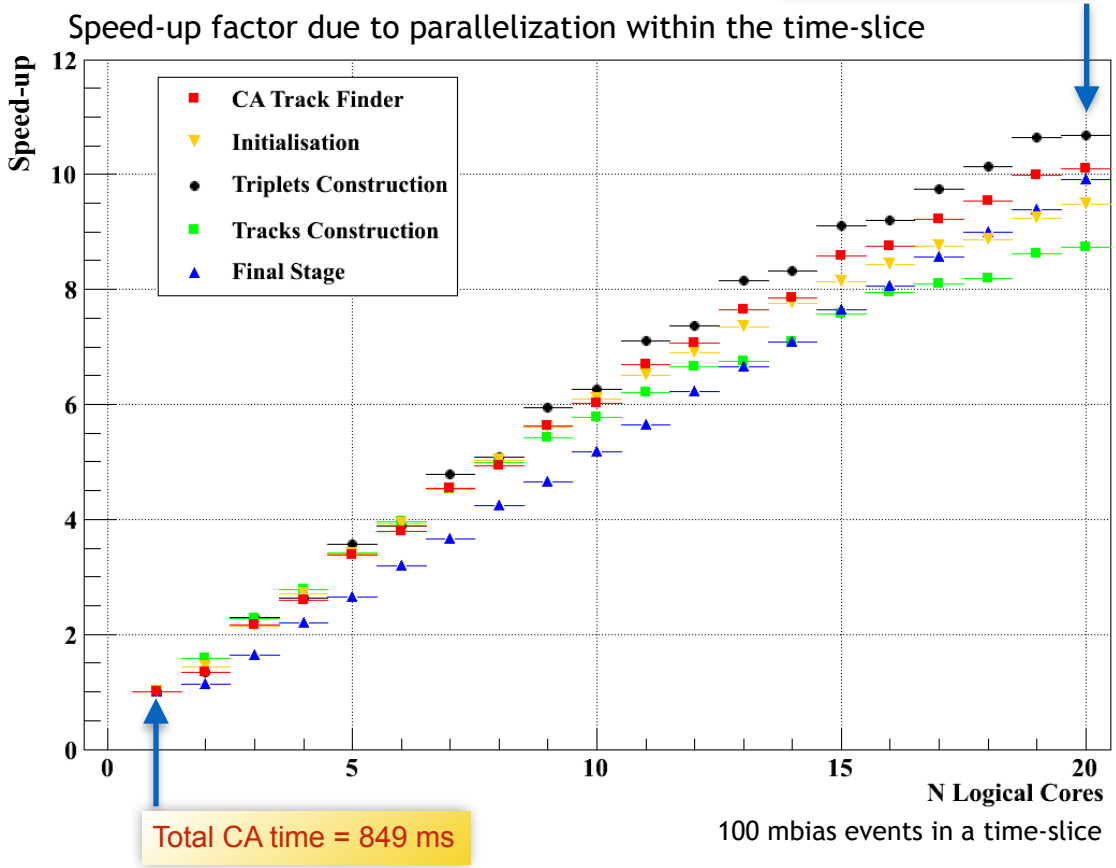
Time-based (4D) Track Reconstruction with CA Track Finder



- The beam in the CBM will have no bunch structure, but continuous.
- Measurements in this case will be 4D (x, y, z, t).
- Significant overlapping of events in the detector system.
- Reconstruction of time slices rather than events is needed.

Stage of the algorithm	% of total execution time
Initialisation	8
Triplets construction	64
Tracks construction	15
Final cleaning	13

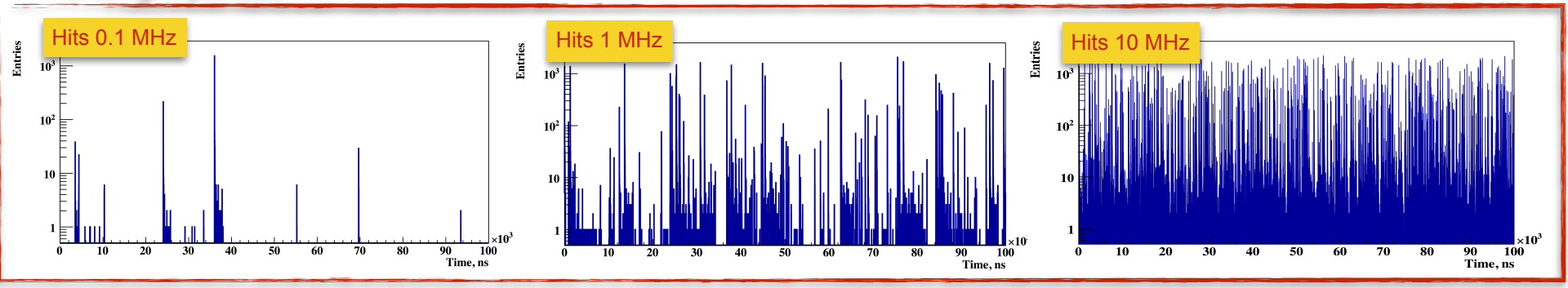
Total CA time = 84 ms



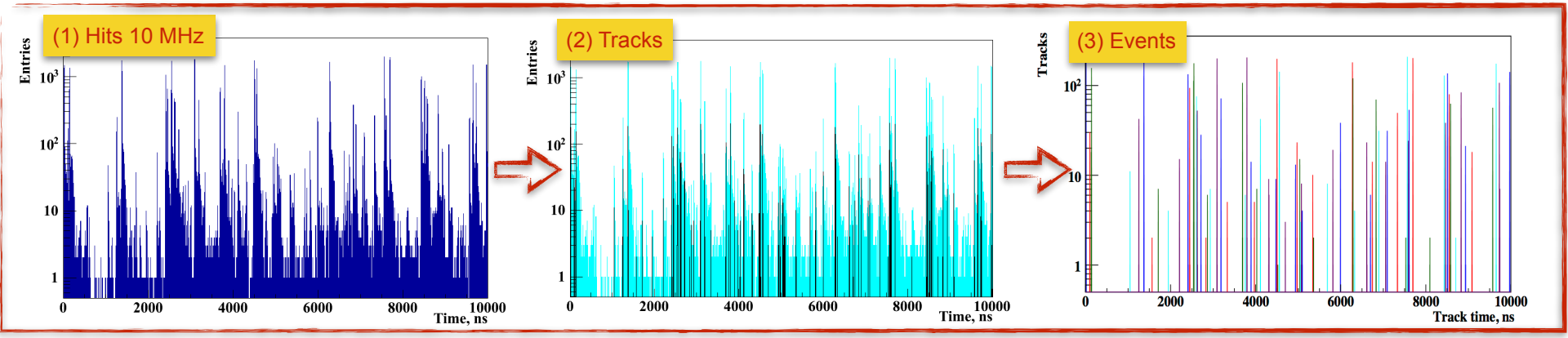
4D event building is scalable with the speed-up factor of 10.1; 3D reconstruction time 8.2 ms/event is recovered in 4D case

4D Event Building at 10 MHz

Hits at high input rates

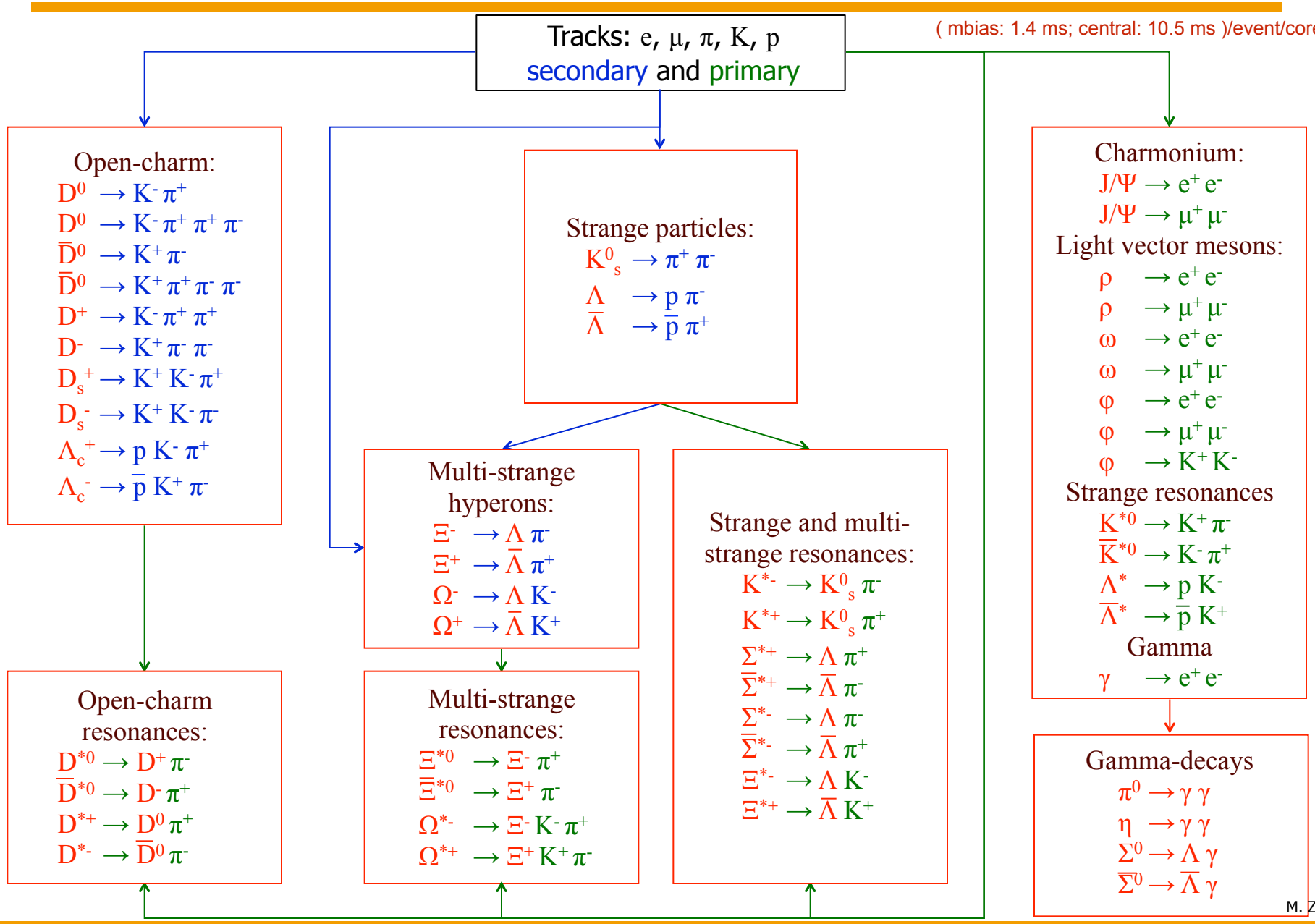


From hits to tracks to events

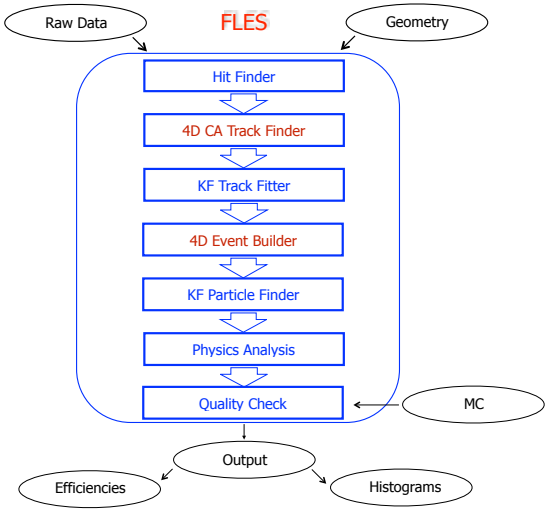


Reconstructed tracks clearly represent groups, which correspond to the original events
83% of single events, no splitted events, further analysis with TOF information at the vertexing stage

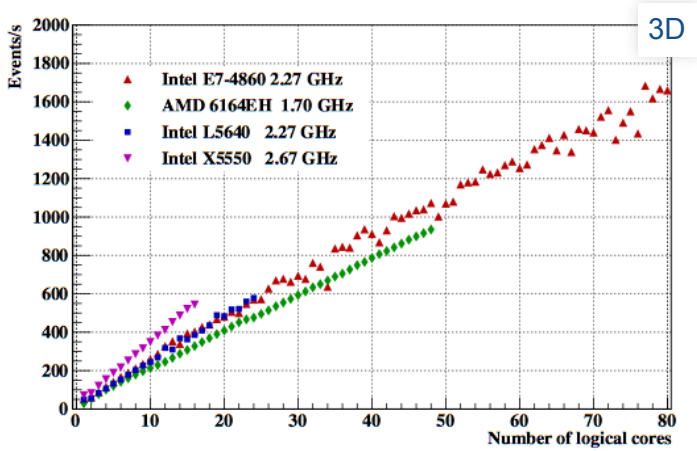
KF Particle Finder for Physics Analysis and Selection

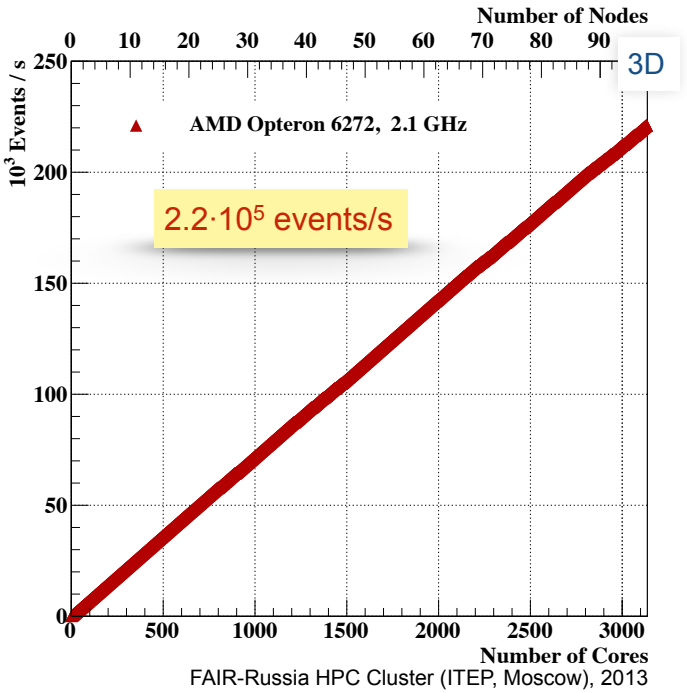


Standalone 4D First-Level Event Selection (FLES) Package



- LOEWE CSC (FIAS, Frankfurt)
- Green Cube (GSI, Darmstadt)
- FAIR-Russia HPC Cluster (ITEP, Moscow)





The first version of the FLES package is vectorized, parallelized, portable and scalable up to 3 200 CPU cores

Summary

- The Kalman Filter track fit library is vectorized, parallelized and portable to CPU/Phi/GPU architectures.
- The Cellular Automaton track finder is vectorized, parallelized and updated for time-based (4D) track finding in time-slices.
- 4D event building is done after all tracks in the time-slice are found.
- The FLES package shows the processing speed of $2.2 \cdot 10^5$ events/s on an HPC cluster with 3 200 CPU cores.