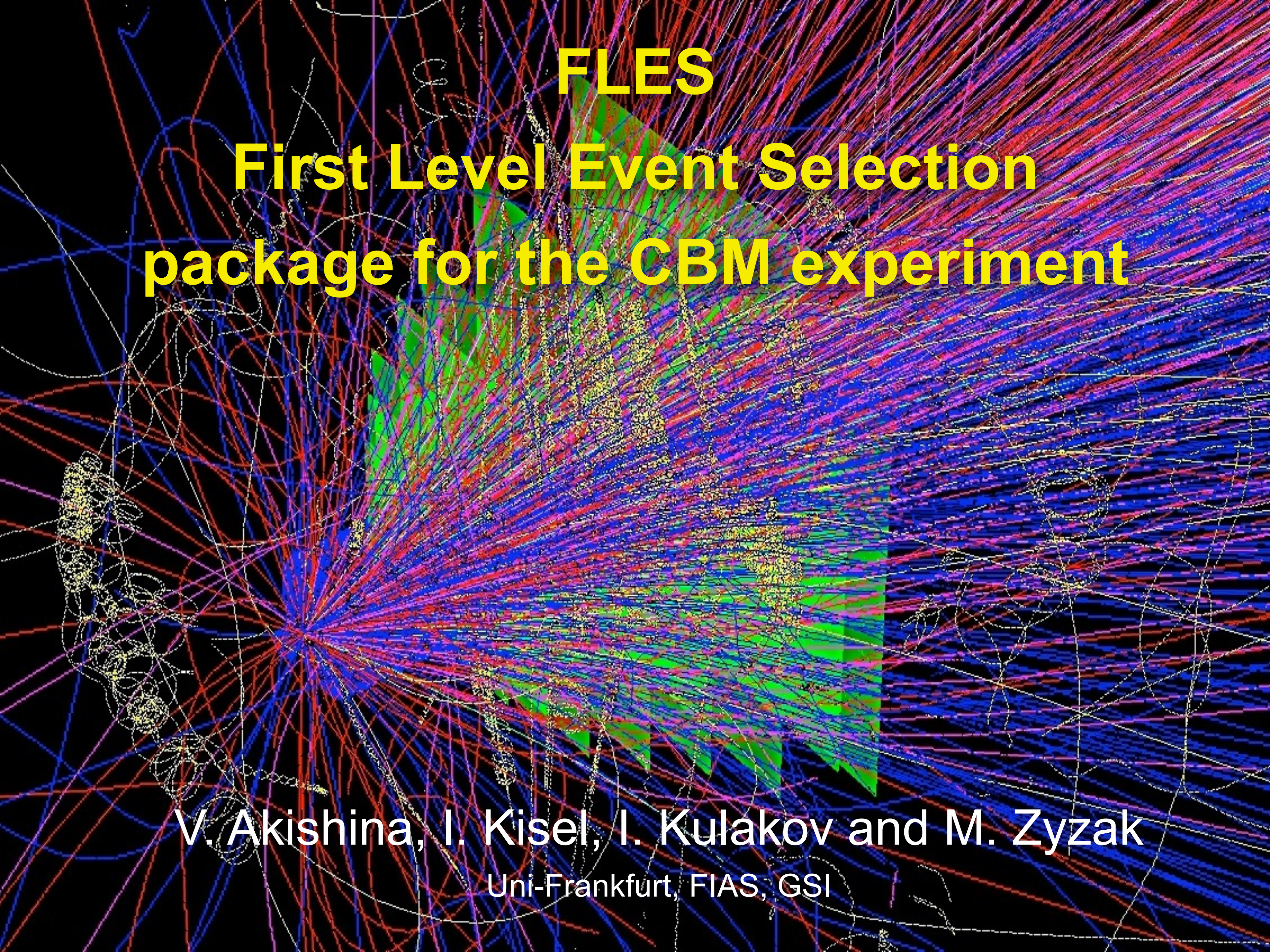
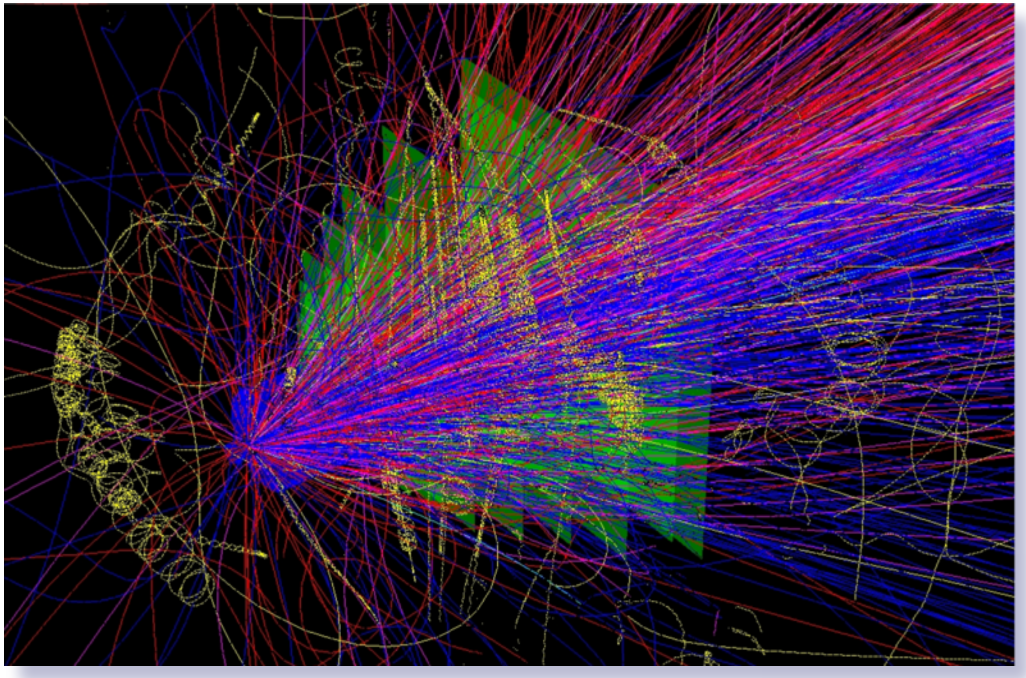


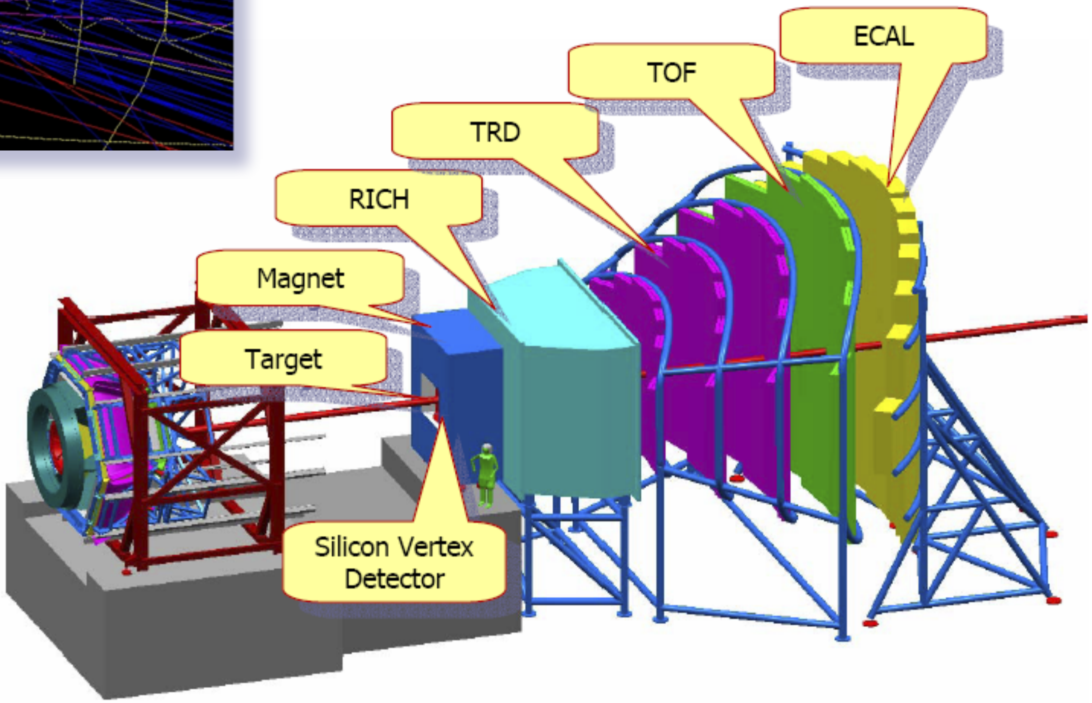
# FLES
# First Level Event Selection package for the CBM experiment

V. Akishina, I. Kisel, I. Kulakov and M. Zyzak
Uni-Frankfurt, FIAS, GSI

# Reconstruction Challenge in CBM

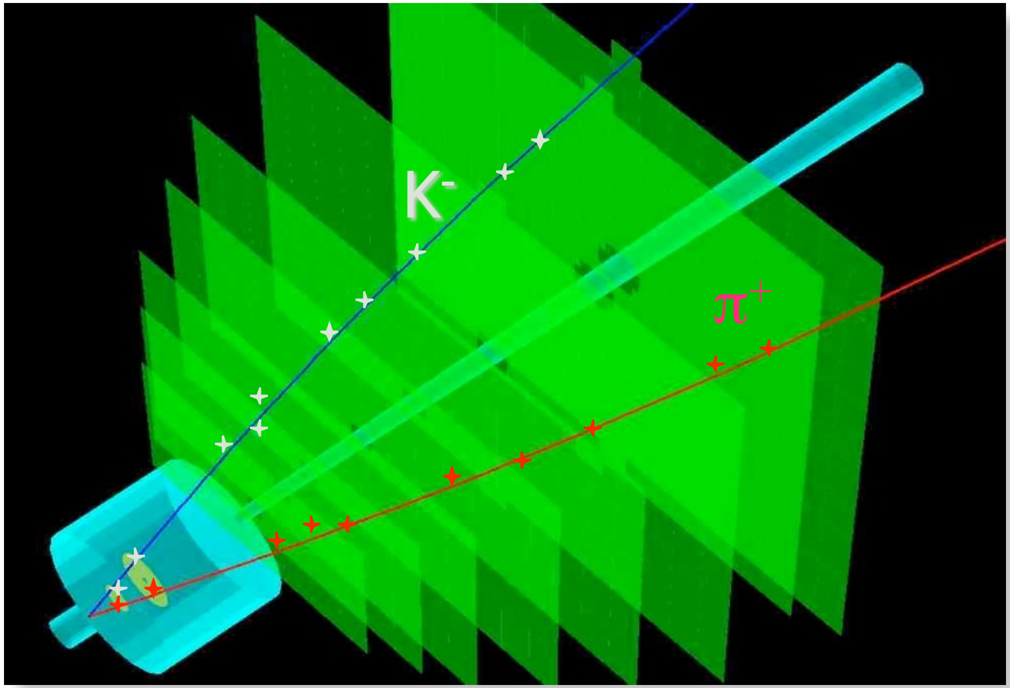


* Fixed-target heavy-ion experiment
* $10^7$ Au+Au collisions/sec
* ~ 1000 charged particles/collision
* Non-homogeneous magnetic field
* Double-sided strip detectors
  (85% fake space-points)




Track reconstruction in STS/MVD
and displaced vertex search
required in the first trigger level

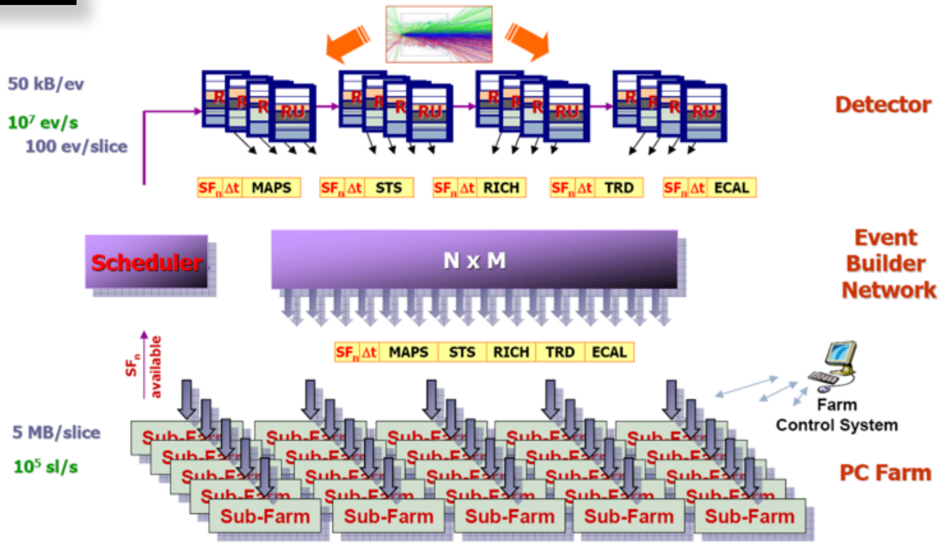
# Open Charm Event Selection




$D^{\pm}$ ($c\tau$ = 312 μm):
$D^+ \rightarrow K^-\pi^+\pi^+$ (9.5%)
$D^0$ ($c\tau$ = 123 μm):
$D^0 \rightarrow K^-\pi^+$ (3.8%)
$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$ (7.5%)
$D^{\pm}_s$ ($c\tau$ = 150 μm):
$D^+_s \rightarrow K^+K^-\pi^+$ (5.3%)
$\Lambda^+_c$ ($c\tau$ = 60 μm):
$\Lambda^+_c \rightarrow pK^-\pi^+$ (5.0%)

No simple trigger primitive, like high $p_t$, available to tag events of interest. The only selective signature is the detection of the decay vertex.

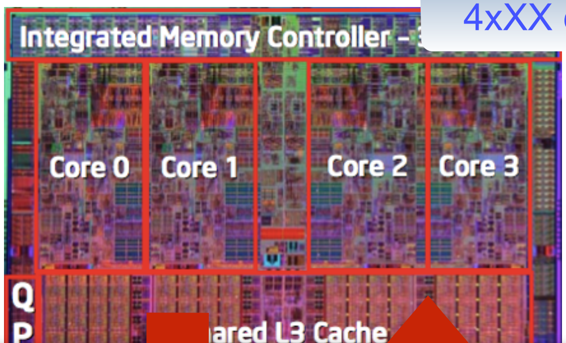
First level event selection will be done in a processor farm fed with data from the event building network



# Many-Core CPU/GPU Architectures

## Intel/AMD CPU

4xXX cores



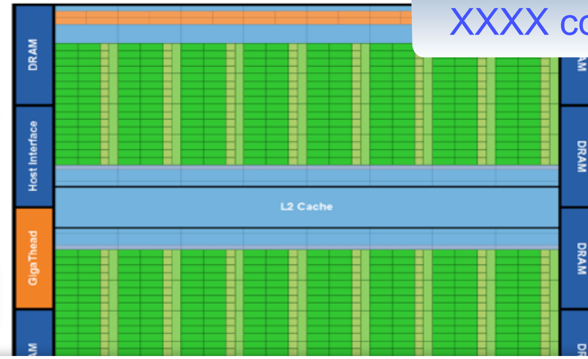

- Optimized for lo tency access ched data sets
- Control logic for -of-order and culative execution

Math

Memory

## Nvidia/ATI GPU

XXXX cores




- Optimized for data-parallel, throughput computation
- re transistors dedicated to computation

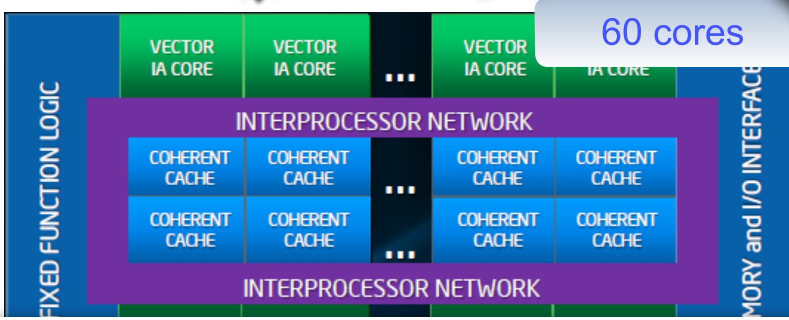
Math

Memory

Stability

## Intel MIC

60 cores

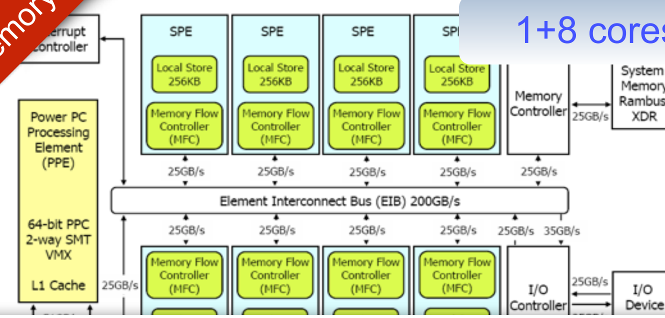



- Many Integrated Cores architecture announced at ISC10 (June 2010)
- Based on the x86 architecture
- Many-cores + 4-way multithreaded + 512-bit wide vector unit

## IBM Cell

1+8 cores

Memory




- General purpose RISC processor (PowerPC)
- 8 co-processors (SPE, Synergistic Processor Elements)
- 128-bit wide SIMD units

Future systems are heterogeneous, but using the same code

# CBM Kalman Filter 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

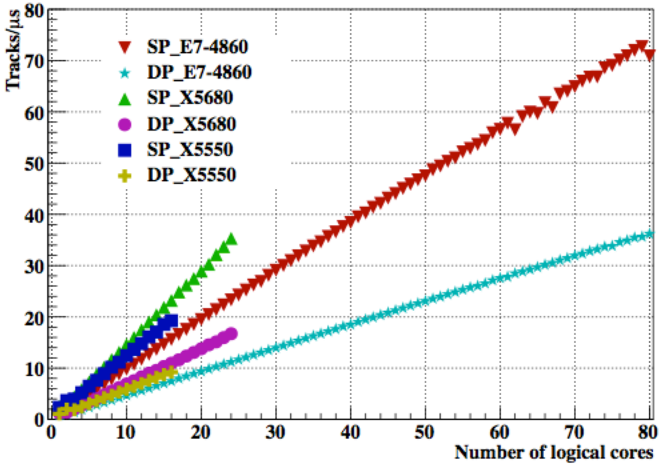
## Implementations

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

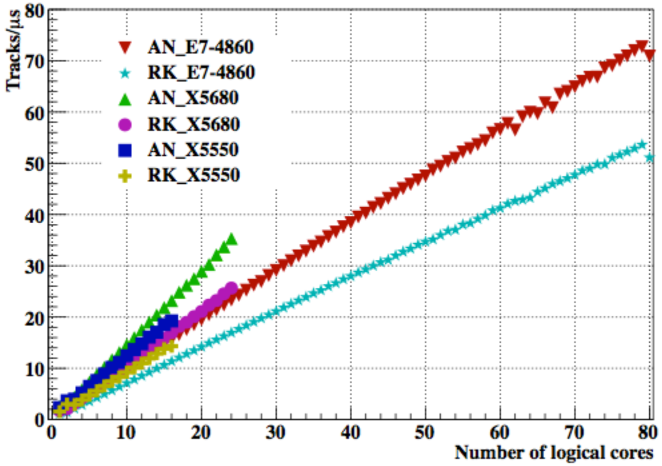
Parallelization (many-cores):
- Open MP
- ITBB
- ArBB
- OpenCL

Precision:
- single
- double

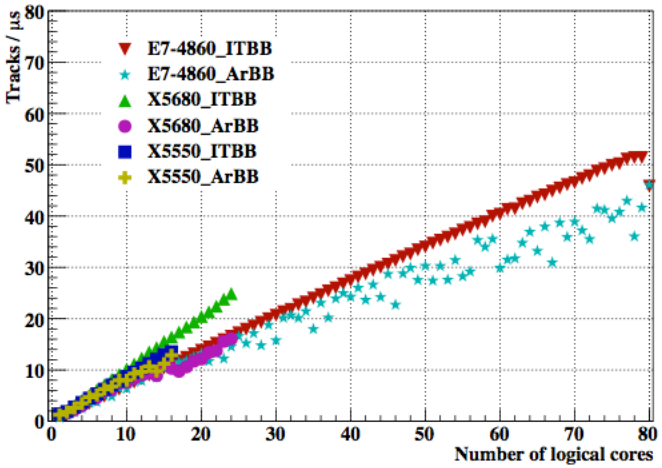
Conventional KF DP vs. SP



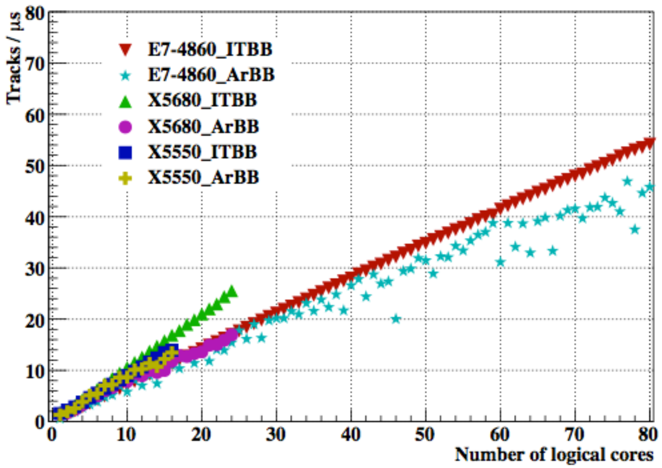

Conventional KF RK4 vs. Analytical




Square-Root KF

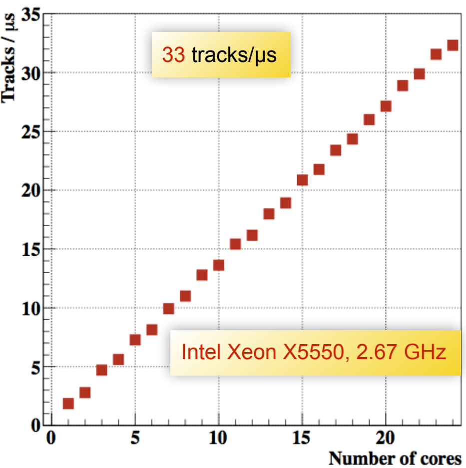


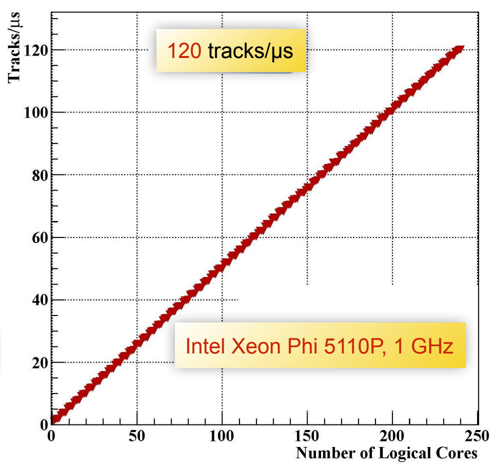

UD KF

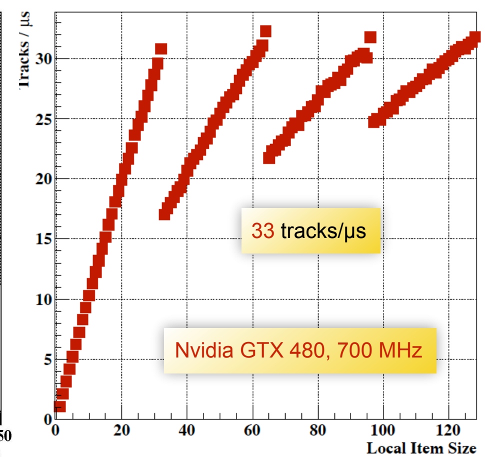


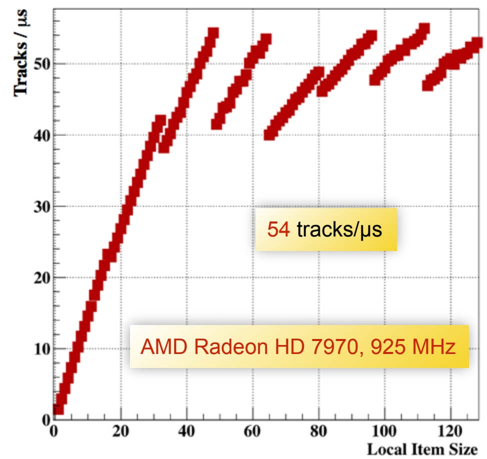

Strong many-core scalability of the Kalman filter library

# CBM Kalman Filter Track Fit Library

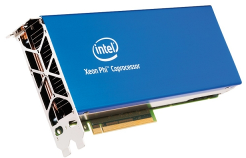


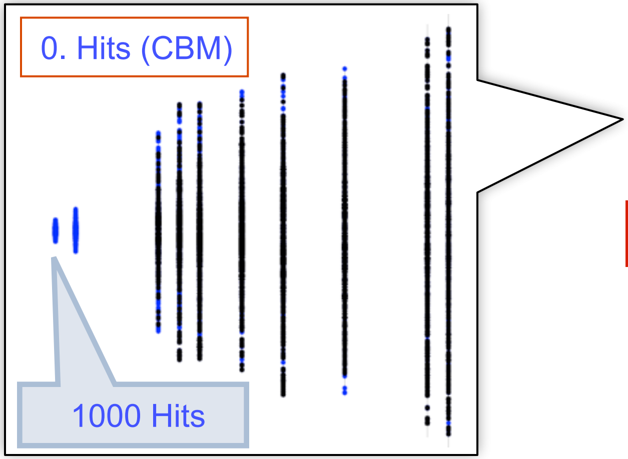



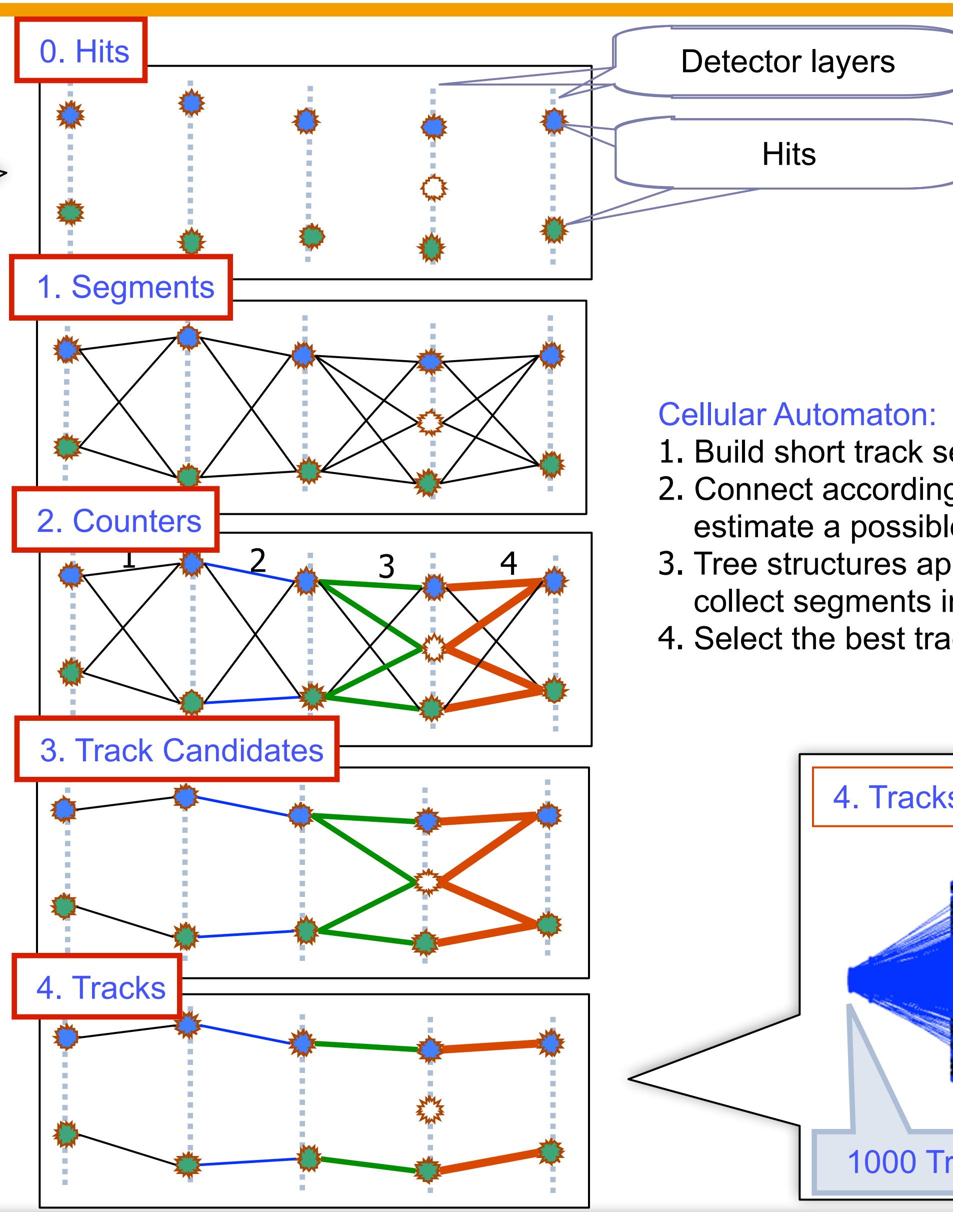




Full portability of the Kalman filter library

# Cellular Automaton as Track Finder

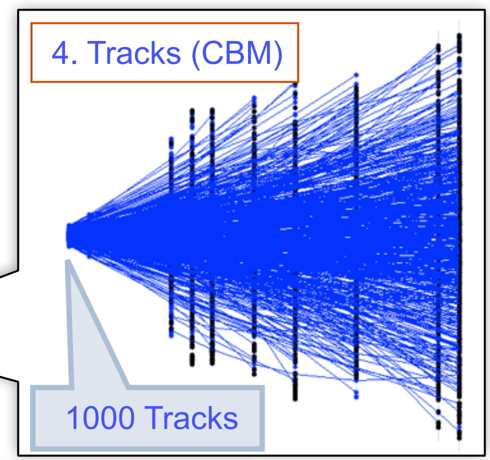



Cellular Automaton:
1. Build short track segments.
2. Connect according to the track model, estimate a possible position on a track.
3. Tree structures appear, collect segments into track candidates.
4. Select the best track candidates.

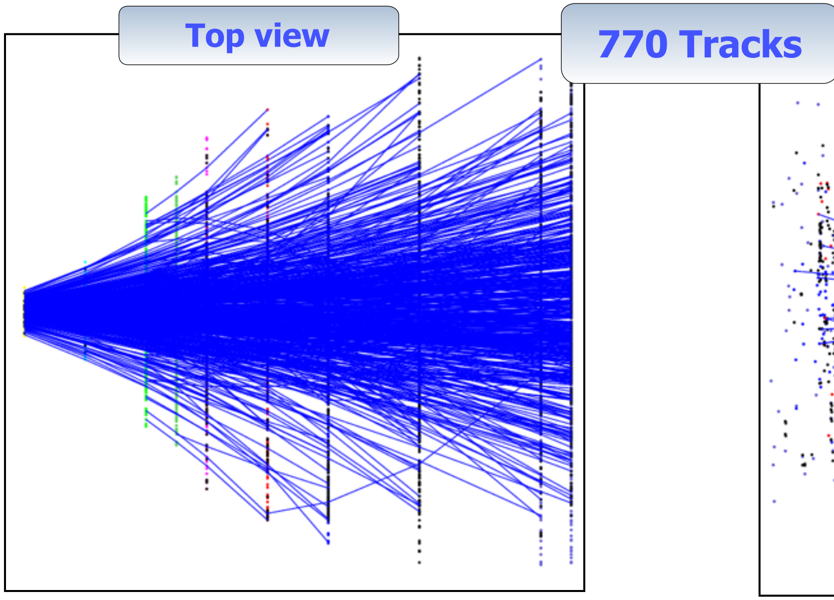
Cellular Automaton:
- local w.r.t. data
- intrinsically parallel
- extremely simple
- very fast

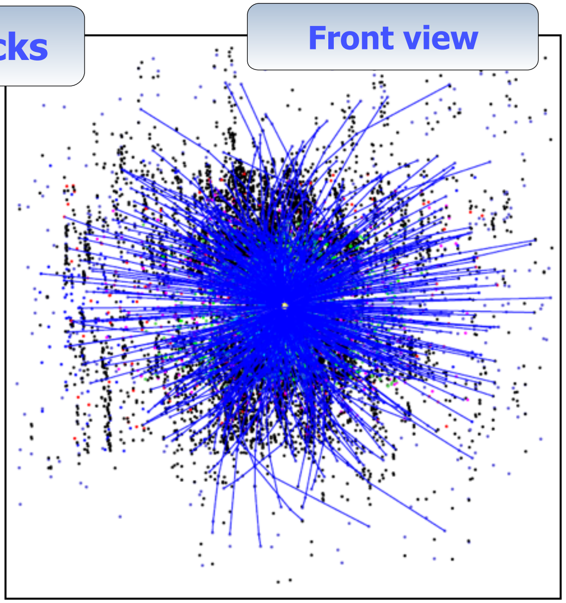
Perfect for many-core CPU/GPU !

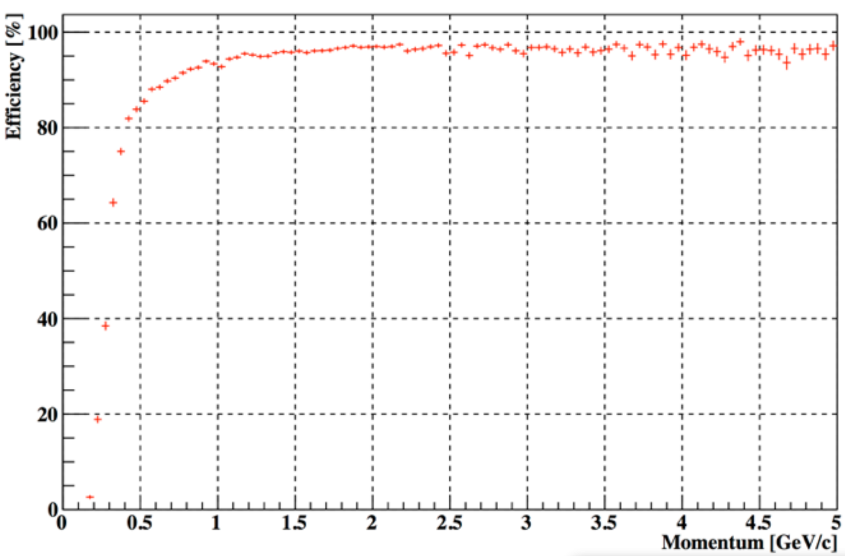



Useful for complicated event topologies with large combinatorics and for parallel hardware

# CBM CA Track Finder: Efficiency



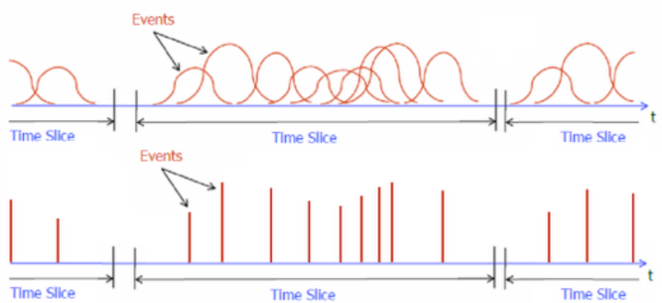



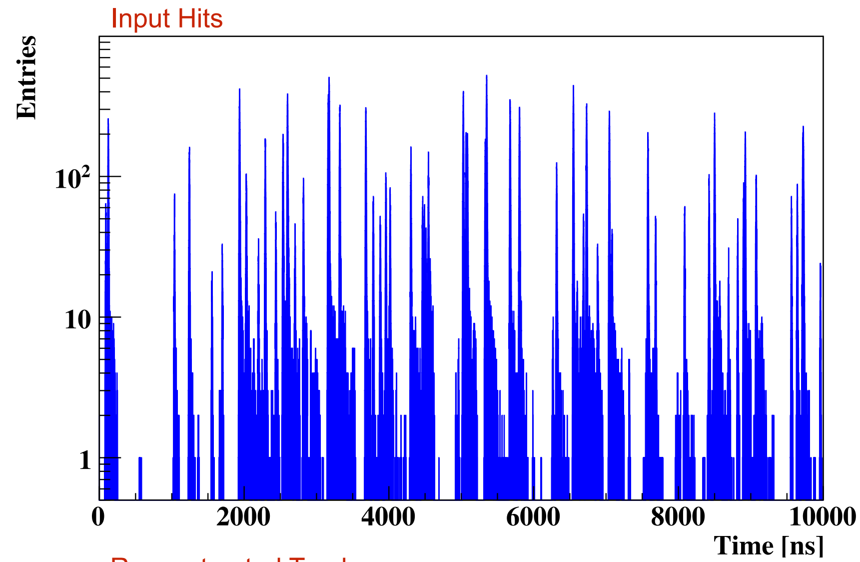

| | Efficiency, % | |
|---|---|---|
| | mbias | central |
| Primary high-$p$ tracks | 97.1 | 96.2 |
| Primary low-$p$ tracks | 90.4 | 90.7 |
| Secondary high-$p$ tracks | 81.2 | 81.4 |
| Secondary low-$p$ tracks | 51.1 | 50.6 |
| All tracks | 88.5 | 88.3 |
| Clone level | 0.2 | 0.2 |
| Ghost level |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

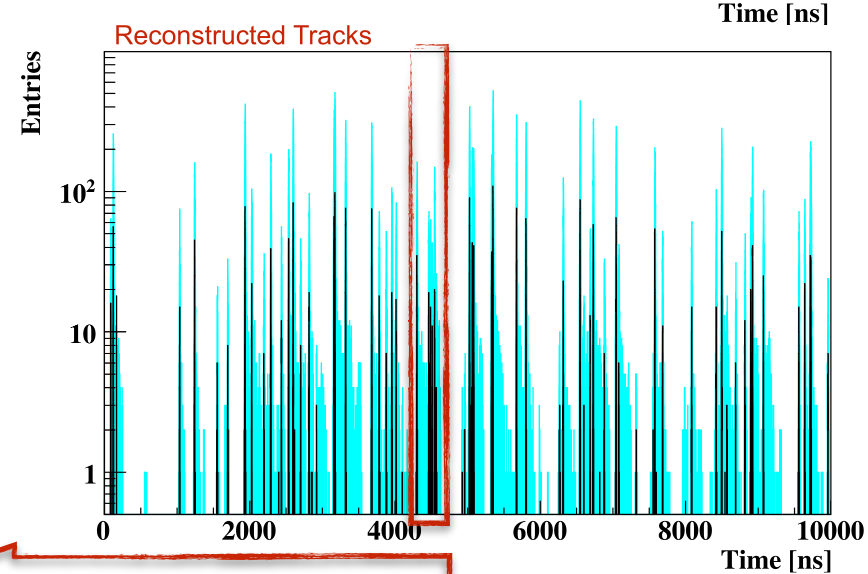
Efficient and stable event reconstruction

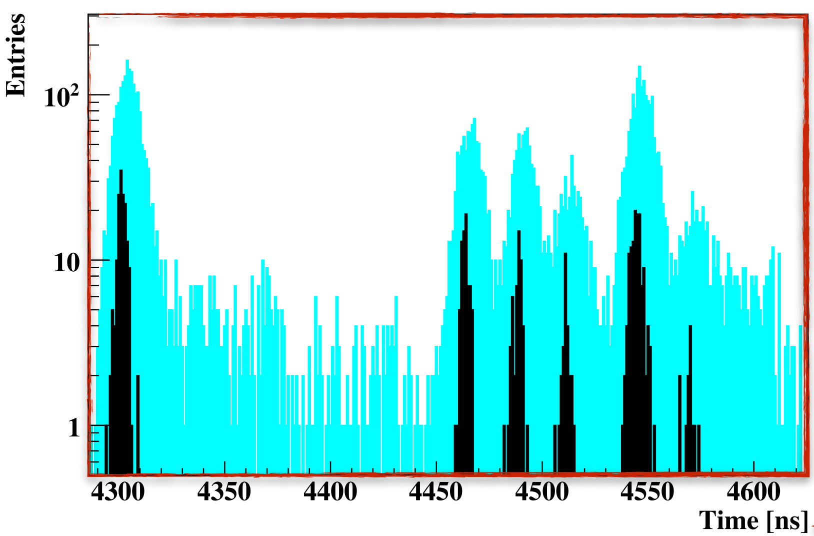
# 4D Event Building with CA Track Finder

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



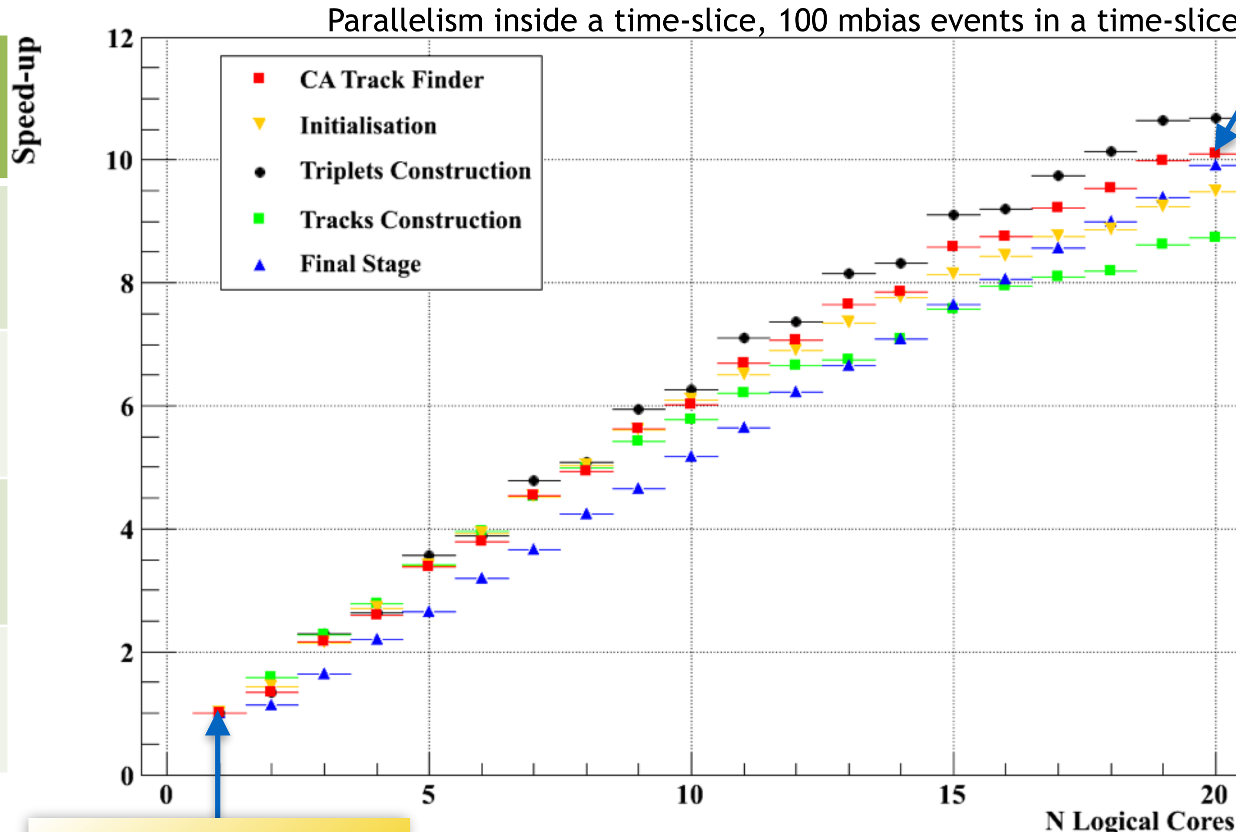




Reconstructed tracks clearly represent groups, which correspond to the original events

# 4D Event Building with CA Track Finder

| Algorithm Step | % of total execution time |
|---|---|
| Initialisation | 8 % |
| Triplets construction | 64 % |
| Tracks construction | 15 % |
| Final stage | 13 % |

Total CA time = 84 ms




Total CA time = 849 ms

4D event building is scalable with the speed-up factor of 10.1 (out of 13)

# KF Particle Finder for Physics Analysis and Selection

Tracks: $e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, $p^\pm$
secondary primary

( mbias: 1.4 ms; central: 10.5 ms )/event/core

Open-charm:
$D^0 \to \pi^+ K^-$
$D^0 \to \pi^+ \pi^+ \pi^- K^-$
$\bar{D}^0 \to \pi^- K^+$
$\bar{D}^0 \to \pi^- \pi^- \pi^+ K^+$
$D^+ \to \pi^+ \pi^+ K^-$
$D^- \to \pi^- \pi^- K^+$
$D_s^+ \to \pi^+ K^+ K^-$
$D_s^- \to \pi^- K^+ K^-$
$\Lambda_c \to \pi^+ K^- p$

Strange particles:
$K^0_s \to \pi^+ \pi^-$
$\Lambda \to p\, \pi^-$
$\bar{\Lambda} \to \pi^+ p^-$

Gamma:
$\gamma \to e^- e^+$
Strange resonances:
$\bar{K}^{*0} \to K^+ \pi^-$
$K^{*0} \to \pi^+ K^-$
$\bar{\Lambda}^* \to p\, K^-$
$\Lambda^* \to p^- K^+$
Light vector mesons:
$\rho \to e^- e^+$
$\rho \to \mu^- \mu^+$
$\omega \to e^- e^+$
$\omega \to \mu^- \mu^+$
$\varphi \to e^- e^+$
$\varphi \to \mu^- \mu^+$
$\varphi \to K^- K^+$
Charmonium:
$J/\Psi \to e^- e^+$
$J/\Psi \to \mu^- \mu^+$

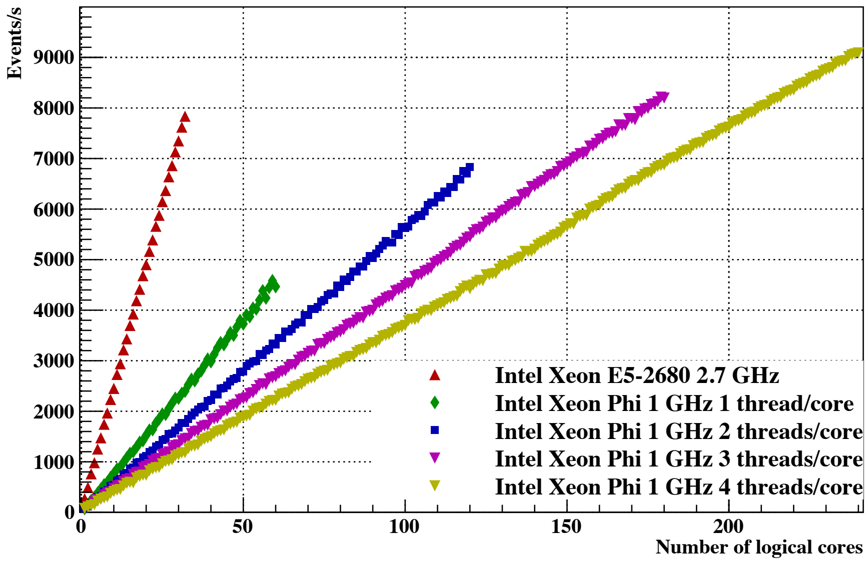
Multi-strange hyperons:
$\Xi^- \to \Lambda \pi^-$
$\bar{\Xi}^+ \to \bar{\Lambda} \pi^+$
$\Omega^- \to \Lambda K^-$
$\bar{\Omega}^+ \to \bar{\Lambda} K^+$

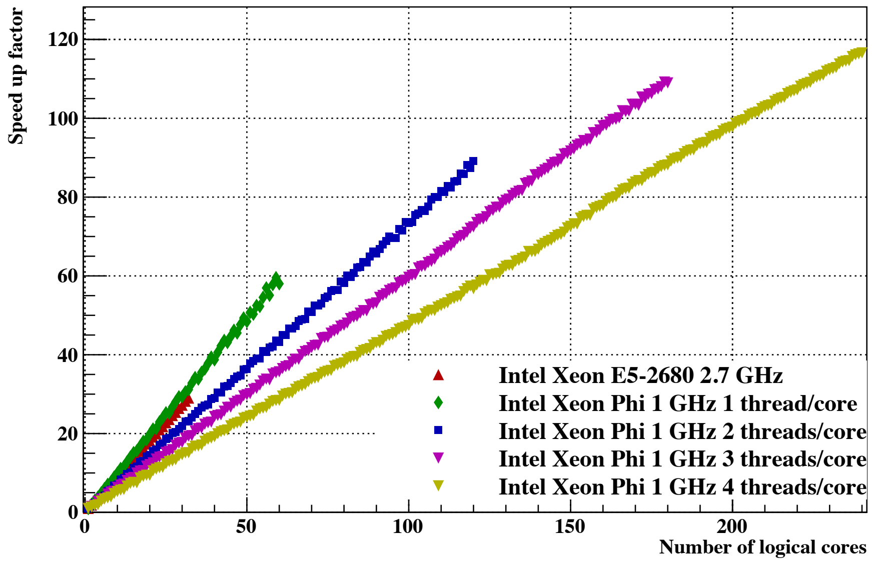
Strange and multi-strange resonances:
$\Sigma^{*+} \to \Lambda \pi^+$
$\bar{\Sigma}^{*+} \to \bar{\Lambda} \pi^-$
$\Sigma^{*-} \to \Lambda \pi^-$
$\bar{\Sigma}^{*-} \to \bar{\Lambda} \pi^+$
$K^{*-} \to K^0_s \pi^-$
$K^{*+} \to K^0_s \pi^+$
$\Xi^{*-} \to \Lambda K^-$
$\Xi^{*+} \to \bar{\Lambda} K^+$

Open-charm resonances:
$D^{*0} \to D^+ \pi^-$
$\bar{D}^{*0} \to D^- \pi^+$
$D^{*+} \to D^0 \pi^+$
$D^{*-} \to \bar{D}^0 \pi^-$

Multi-strange resonances:
$\Xi^{*0} \to \Xi^- \pi^+$
$\bar{\Xi}^{*0} \to \bar{\Xi}^+ \pi^-$
$\Omega^{*-} \to \Xi^- \pi^+ K^-$
$\Omega^{*+} \to \bar{\Xi}^+ \pi^- K^+$

# KF Particle Finder on Xeon Phi



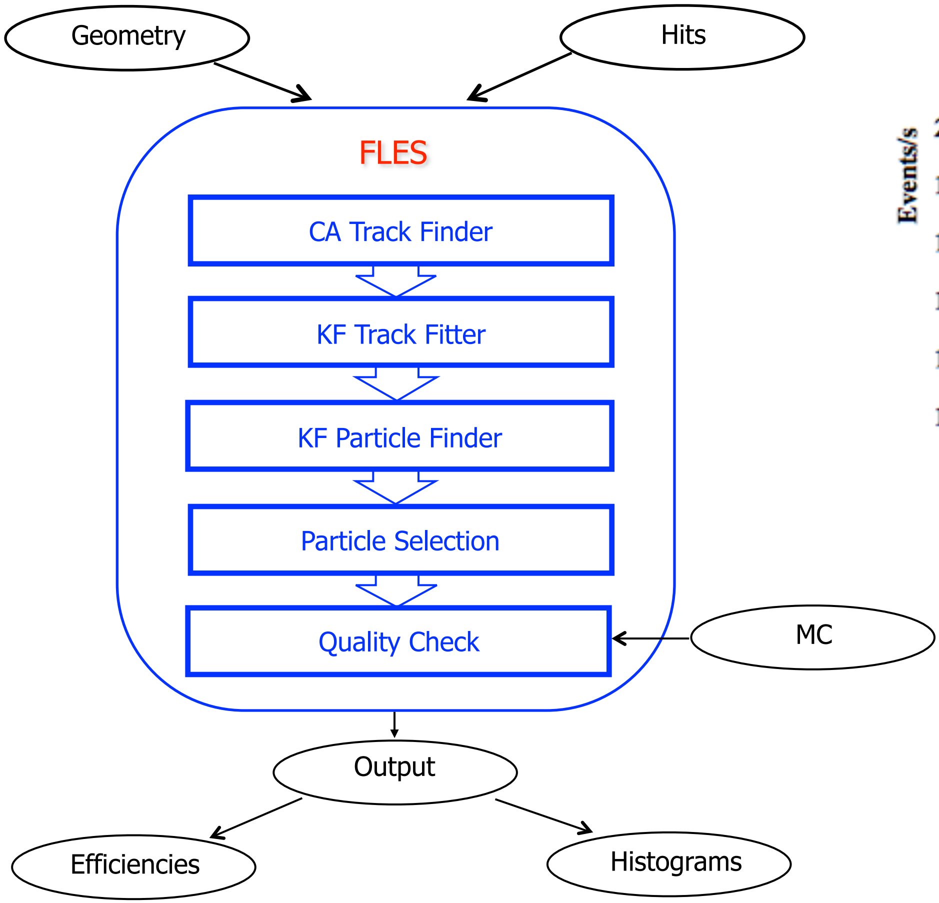



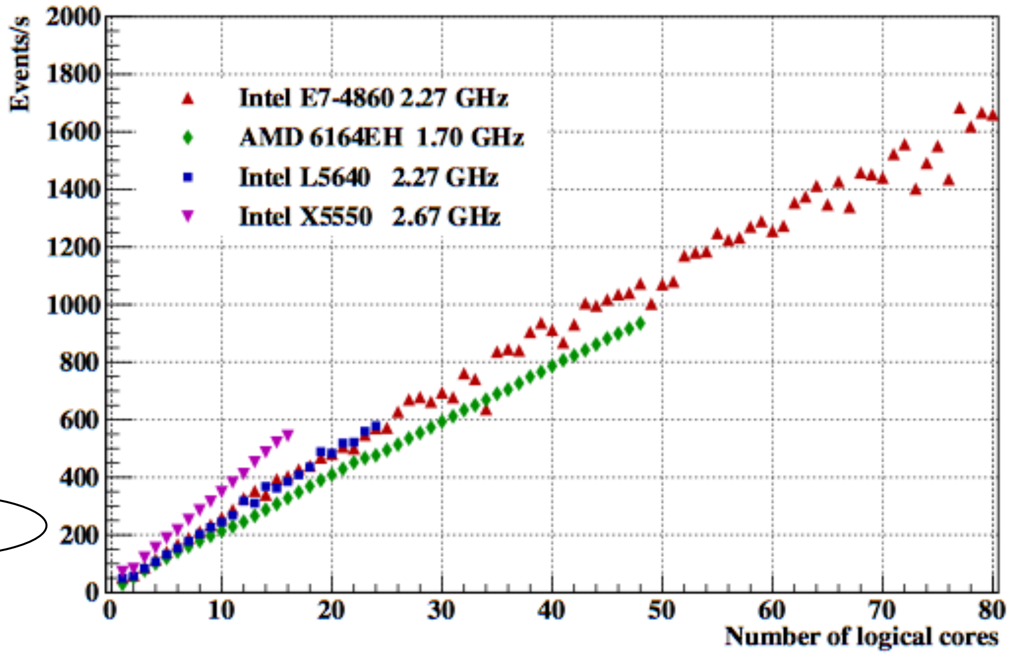

- Standalone KF Particle Finder is adapted for the Xeon Phi card. The same code is used for the CPU and the Xeon Phi.
- The program is tested on search for $K_s^0$, $\Lambda$, $\Xi^-$ and $\Omega^-$ particles.
- The parallelism between cores is implemented on the event level and tested with 100 U+U mbias events per thread.
- The program scales up to 240 logical cores on the Xeon Phi.
- Time per one thread: CPU - 3.7 ms, Xeon Phi - 12.8 ms.
- SIMD Speedup: SSE (CPU, 4 elements) - 3.67, AVX (CPU, length 8) - 4.67, IMIC (Xeon Phi, length 16) - 8.43.

KF Particle Finder is scalable with the speed-up factor of 120 on 240 logical cores.

STAR HLT

# CBM Standalone First Level Event Selection (FLES) Package

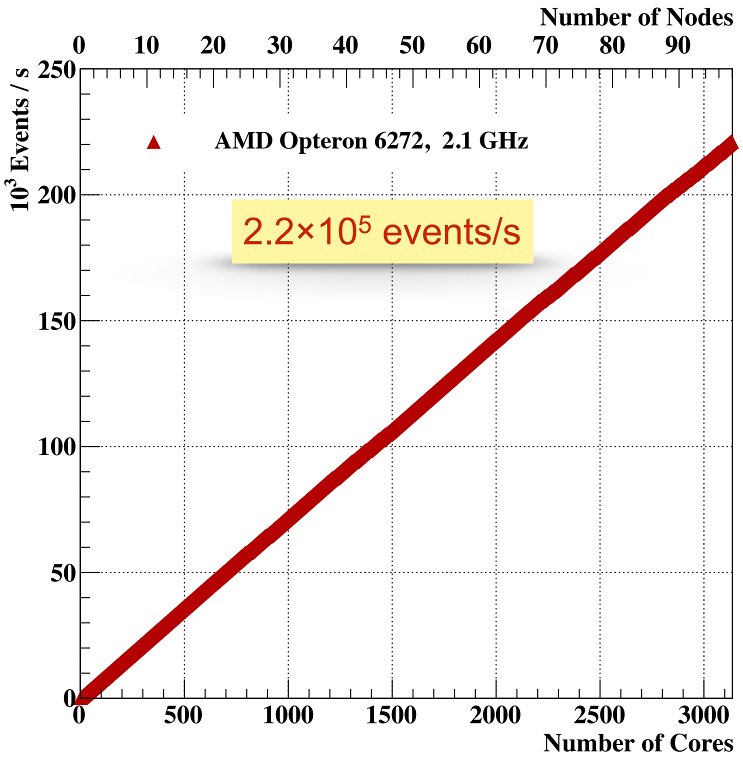



Given n threads each filled with 1000 events, run them on specified n cores, thread/core.

The first version of the FLES package is vectorized, parallelized, portable and scalable

# Towards CBM FLES Demonstrator




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

From cores to the CBM FLES farm with 60 000 cores

# Parallelization in the CBM Event Reconstruction

CPU - Full reconstruction

CPU - Tracking

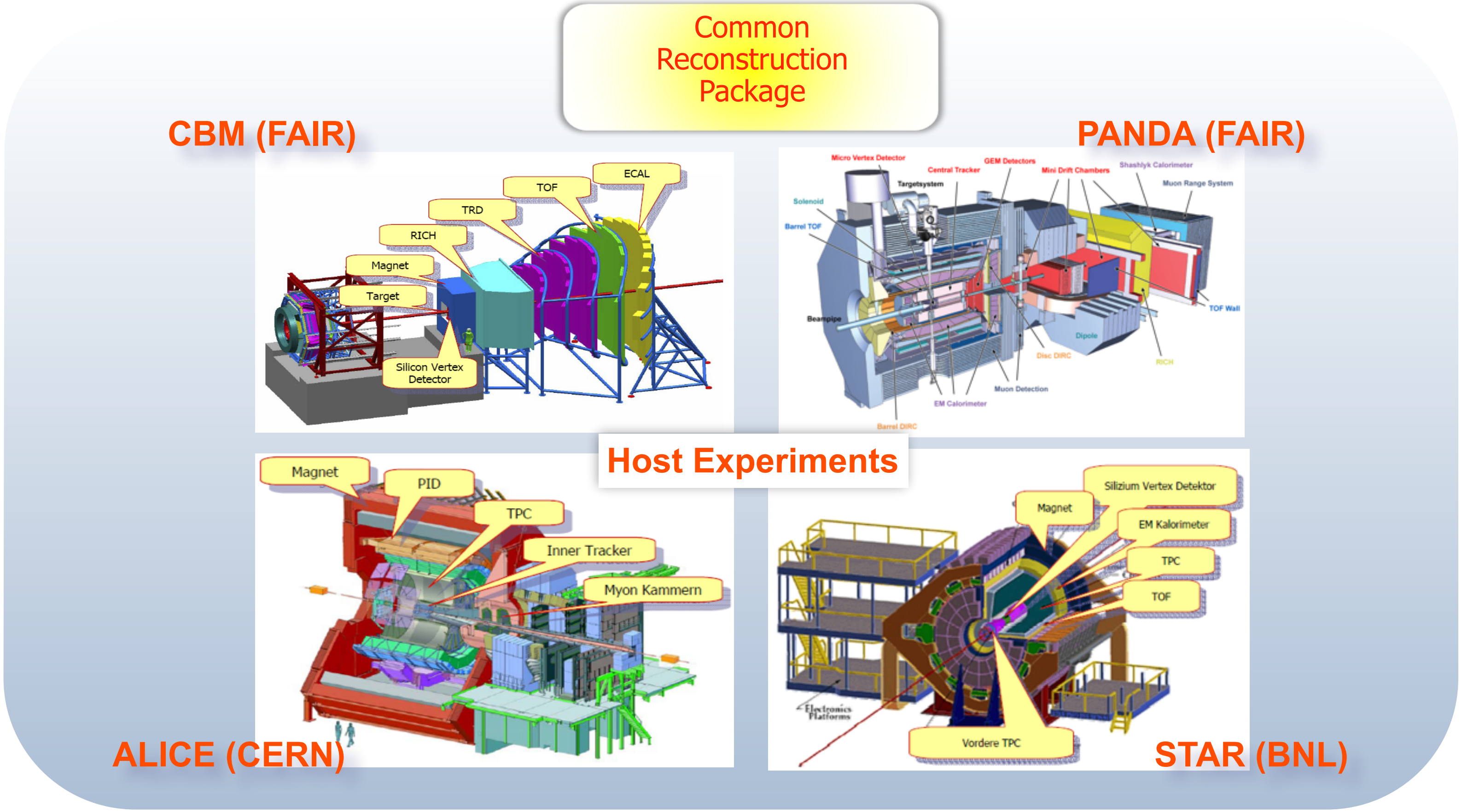
All - Benchmark

GPU/Phi - Selection

| Algorithm | SIMD | ITBB, OpenMP | CUDA | OpenCL CPU/GPU | Phi | ArBB |
|---|---|---|---|---|---|---|
| Hit Producers | | | | | | |
| STS KF Track Fit | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| STS CA Track Finder | ✓ | ✓ | | | | |
| MuCh Track Finder | ✓ | ✓ | ✓ | | | |
| TRD Track Finder | ✓ | ✓ | ✓ | | | |
| RICH Ring Finder | ✓ | ✓ | | ✓ | | |
| KF Particle Finder | ✓ | ✓ | | ✓ | ✓ | |
| Off-line Physics Analysis | ✓ | | | | | |
| FLES Analysis and Selection | ✓ | ✓ | | | | |

Parallelization becomes a standard in the CBM experiment

# Consolidate Efforts: Common Reconstruction Package




- Create a common FAIR reconstruction package
- Use also in running experiments (ALICE, STAR, …)
- Optimize for many-core CPU/GPU/Phi architectures
- Hide parallelism and keep the traditional form of physics analysis

# Consolidate Efforts: International Workshops FCTTC

International Workshops for **F**uture **C**hallenges in **T**racking and **T**rigger **C**oncepts

| | | |
|---|---|---|
| 1st | GSI, Darmstadt, Germany, | 07-11.06.2010; |
| 2nd | CERN, Geneva, Switzerland, | 07-08.07.2011; |
| 3rd | FIAS, Frankfurt, Germany, | 27-29.02.2012; |
| 4th | CERN, Geneva, Switzerland, | 28-30.11.2012; |
| 5th | FIAS, Frankfurt, Germany, | 12-14.05.2014; |
| 6th | not yet fixed, | April 2015. |

# Conclusion

For efficient use of many-core architectures
we need to combine experience of physicists, computer scientists and CPU/GPU/Phi developers.