4D Reconstruction of Time-slices in CBM

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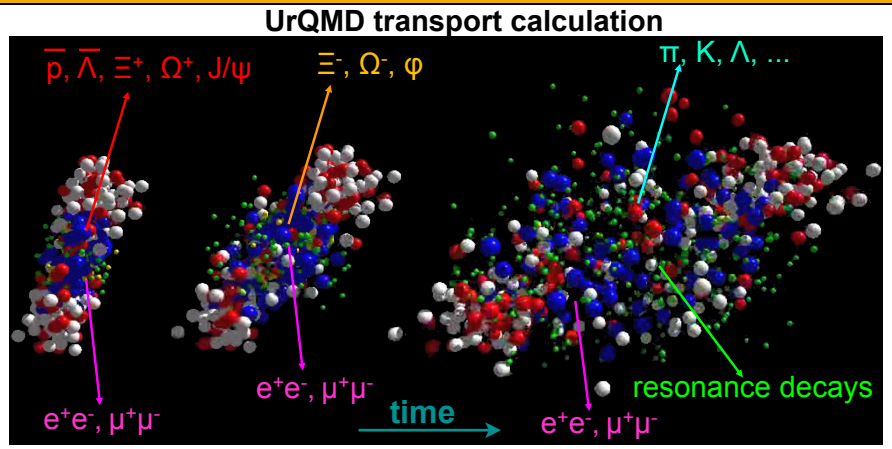
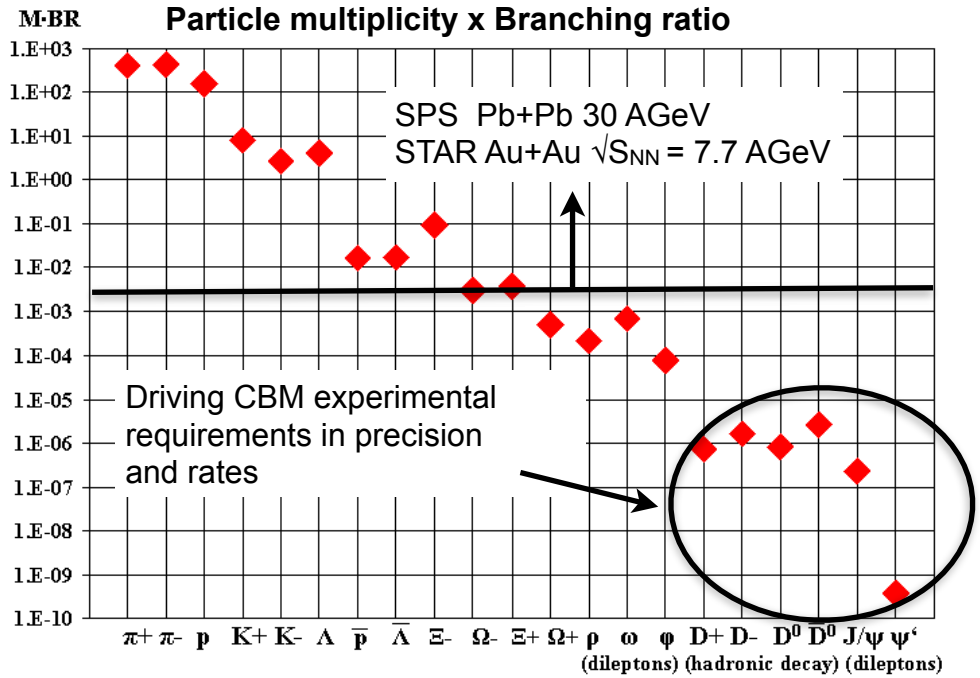
MMCP 2017

CBM: High Interaction Rate Challenge

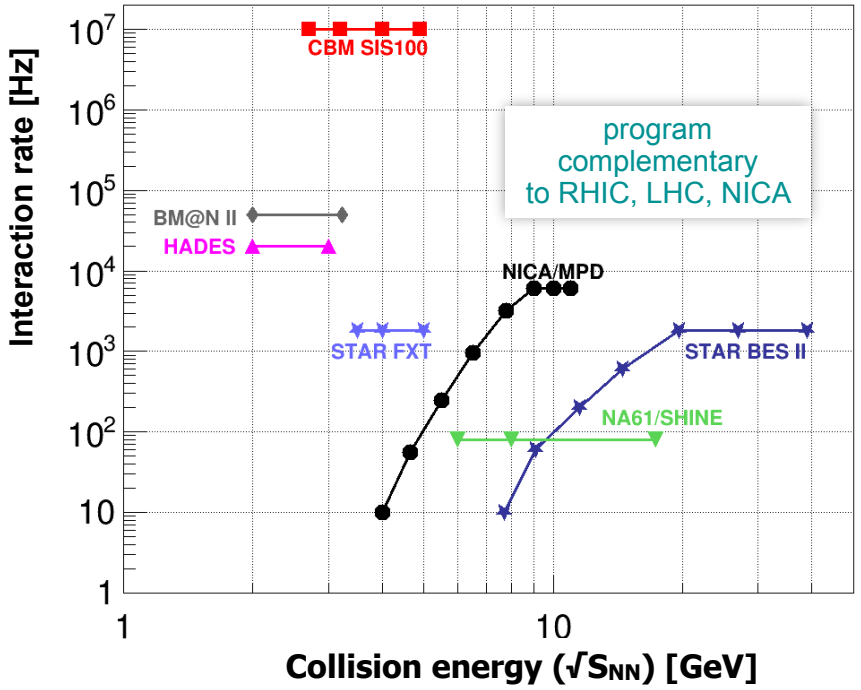
Compressed Baryonic Matter @ FAIR:
high net baryon density, moderate T

- investigation of the baryonic matter phase diagram
- in the laboratory recreate compressed matter in A+A collisions at 2-14 AGeV
- particle production is sensitive to different stages of the collision and states of the baryonic matter



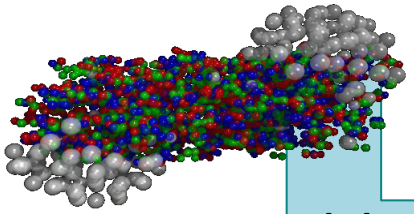


HSD and thermal model minimum bias Au+Au collisions at 25 AGeV



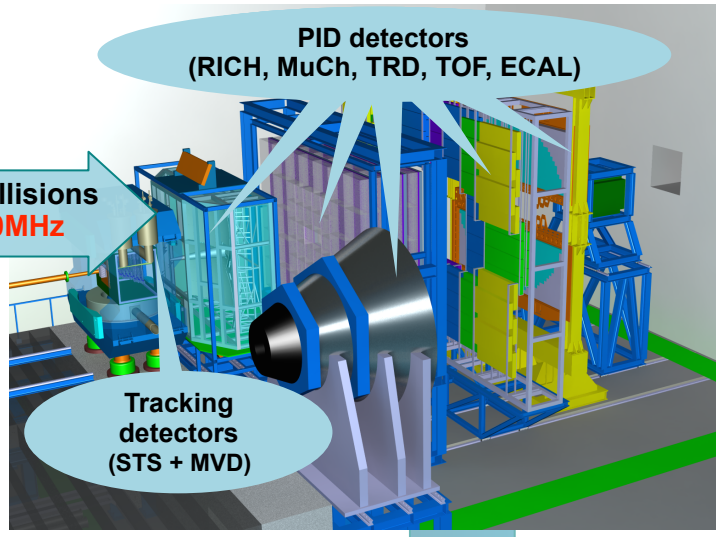
CBM observables include rare probes.
Measurement of rare probes requires extreme interaction rates.

Online Reconstruction in CBM

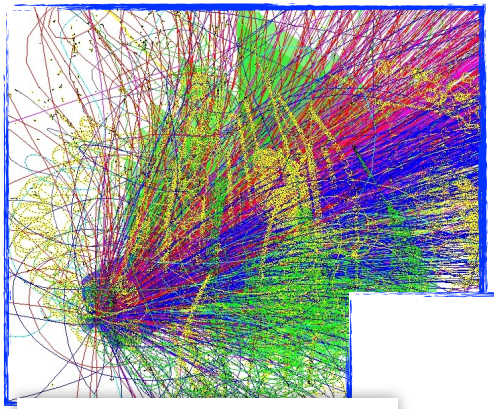


A+A collisions at 10MHz

CBM Detector Setup



- Interaction rate up to 10 MHz
- free-streaming data
- self-triggered front-end electronics
- no hardware trigger



simulated AuAu UrQMD collision at 25 *A*GeV

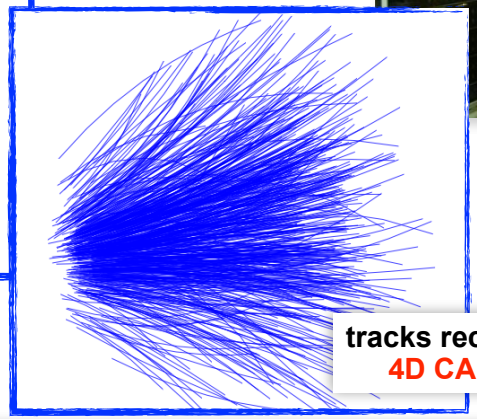
~ 1 TB/s dataflow

FLES prototype: Loewe CSC Frankfurt

~ 1 GB/s dataflow

Mass storage

CBM STS detector hits



tracks reconstructed with 4D CA Track Finder

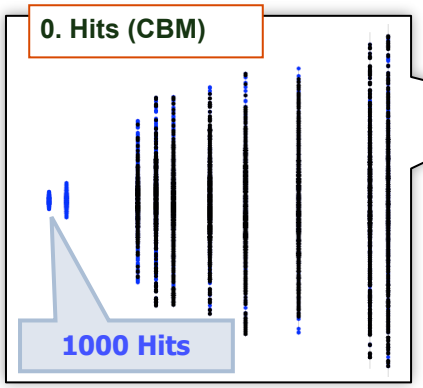
Limited bandwidth of data storing leads to online event reconstruction and selection on a dedicated computer farm.

Cellular Automaton (CA) Track Finder

Track finding: pattern recognition problem
Which hits in detector belong to the same track?

combinatorial task: time-consuming!

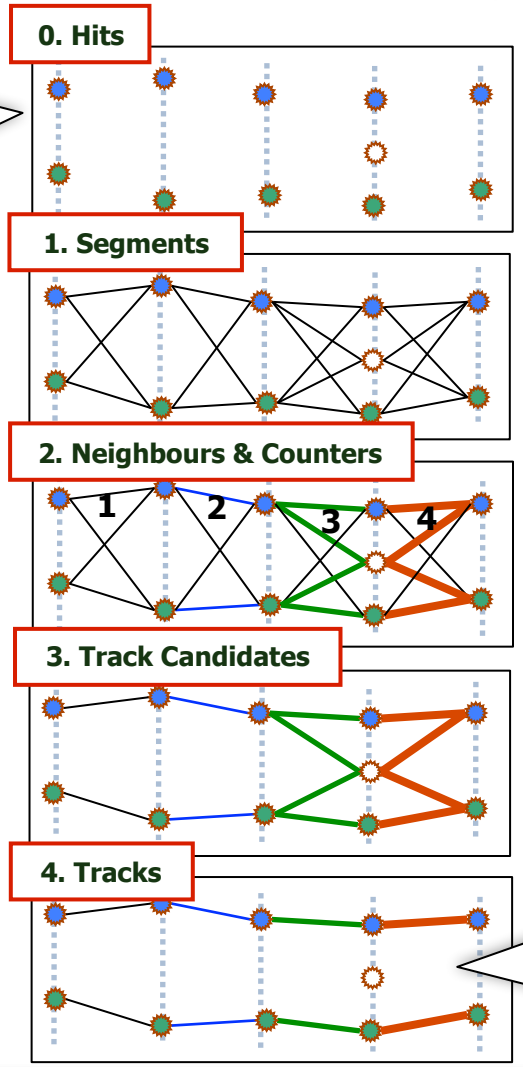
CA solution: combine short track segments instead of hits.

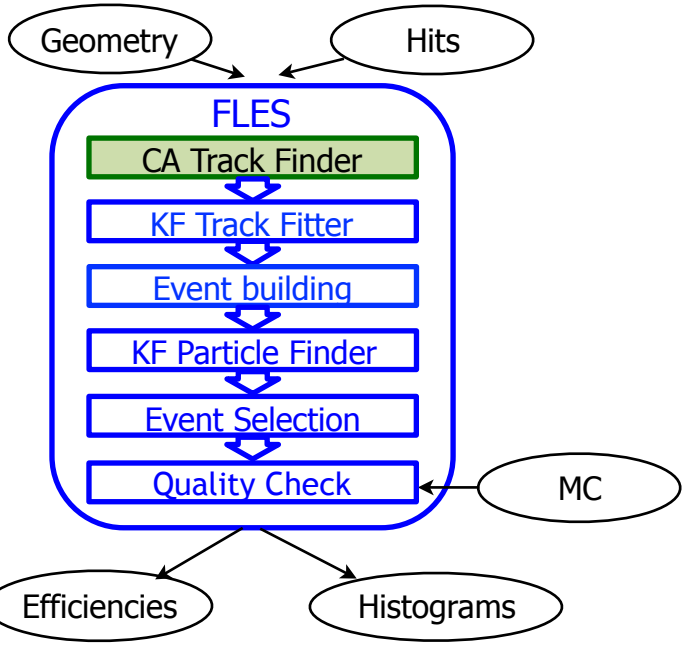


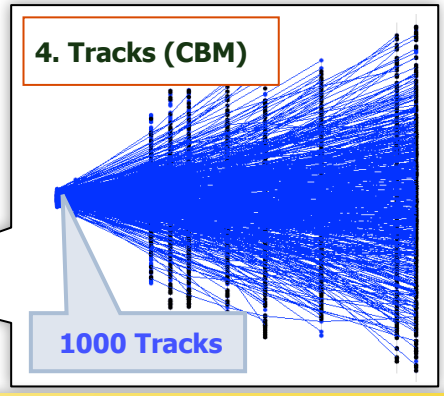
Cellular Automaton:

- efficient and fast
- local w.r.t. data
- intrinsically parallel

Perfect for many-core CPU/GPU !







1. Build **cells** based on the track model. Switch from hits to cells.
2. Find **neighbouring** cells. Connect cells based on the track model. Estimate cell position on a track.
3. Bind cells into track candidates.
4. Select the best track candidates.

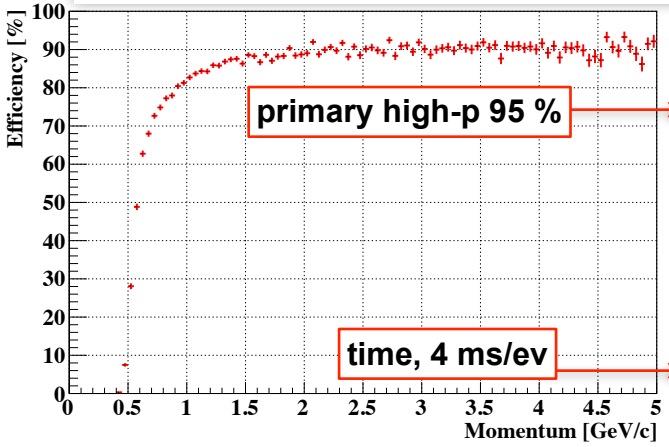
The CA track finder benefits from combinatorics suppression by building up short track segments before starting the main combinatorial enumeration.

CBM CA Track Finder Stages

reconstructable particle: crosses at least 4 consecutive detector stations, p > 100 MeV
reconstructed particle: 70% hits produced by the same and only particle
clone: particle reconstructed two times

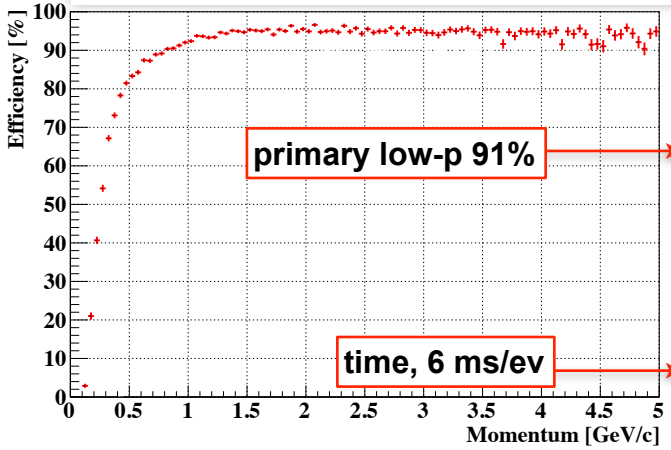
$$\varepsilon = \frac{\text{n reconstructed particles}}{\text{n reconstructable particles}}$$

(iteration **1**) high-momentum primary tracks



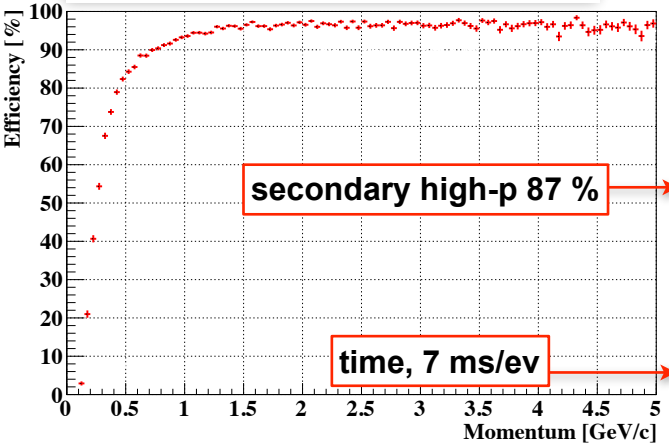
Track category	Eff, %
All tracks	70.4
Primary high-p	94.9
Primary low-p	56.8
Secondary high-p	49.7
Secondary low-p	13.0
Clone level	0.3
Ghost level	0.3
MC tracks found	103
Time, ms/ev	4

(iteration **2**) low-momentum primary tracks



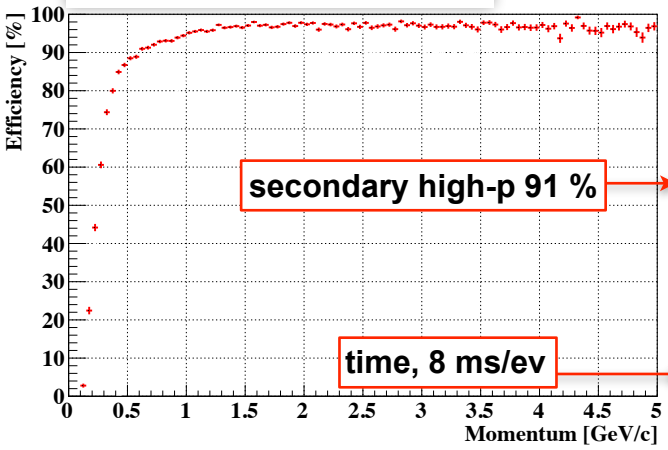
Track category	Eff, %
All tracks	87.8
Primary high-p	95.8
Primary low-p	91.4
Secondary high-p	84.5
Secondary low-p	54.2
Clone level	0.9
Ghost level	5.6
MC tracks found	129
Time, ms/ev	6

(iteration **3**) secondary tracks



Track category	Eff, %
All tracks	89.2
Primary high-p	97.5
Primary low-p	92.4
Secondary high-p	86.6
Secondary low-p	54.7
Clone level	1.0
Ghost level	5.5
MC tracks found	131
Time, ms/ev	7

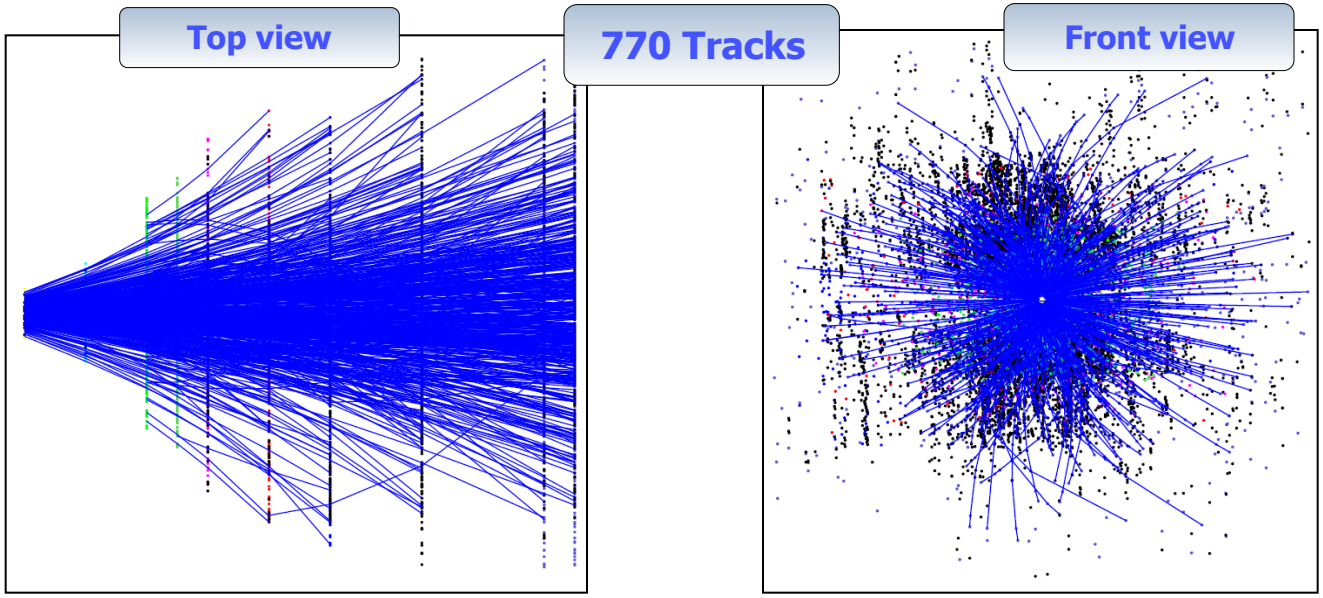
(iteration **4**) broken tracks

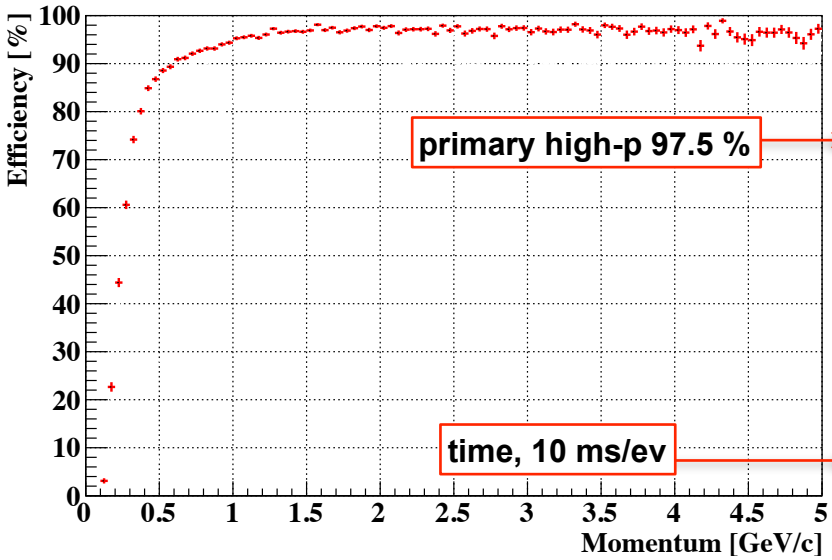


Track category	Eff, %
All tracks	90.9
Primary high-p	97.5
Primary low-p	92.6
Secondary high-p	91.1
Secondary low-p	63.8
Clone level	1.0
Ghost level	5.9
MC tracks found	134
Time, ms/ev	8

Efficient and fast track reconstruction achieved due to iterative algorithm.

CBM CA Track Finder Efficiency

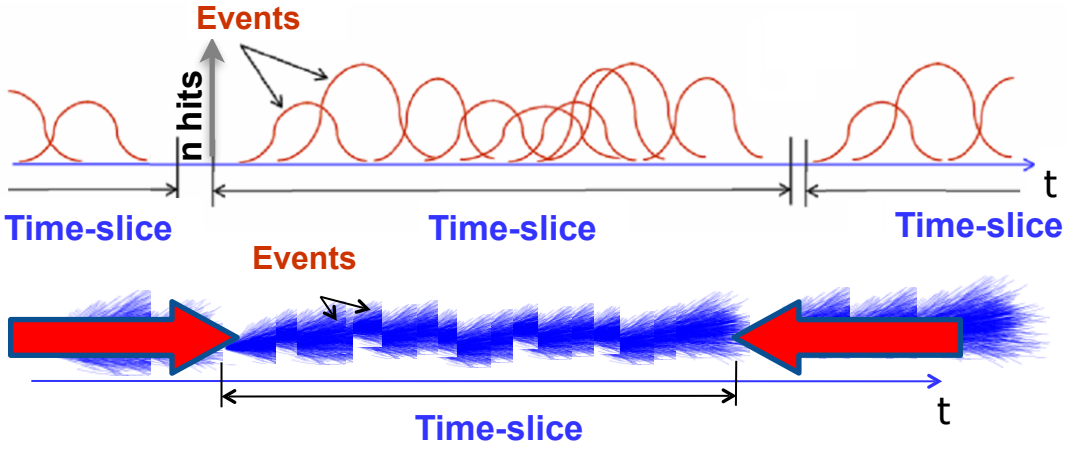




Track category	Eff, %
All tracks	90.9
Primary high-p	97.5
Primary low-p	92.6
Secondary high-p	91.1
Secondary low-p	63.8
Clone level	0.4
Ghost level	5.9
MC tracks found	134
Time, ms/ev	10

Efficient and stable track reconstruction.

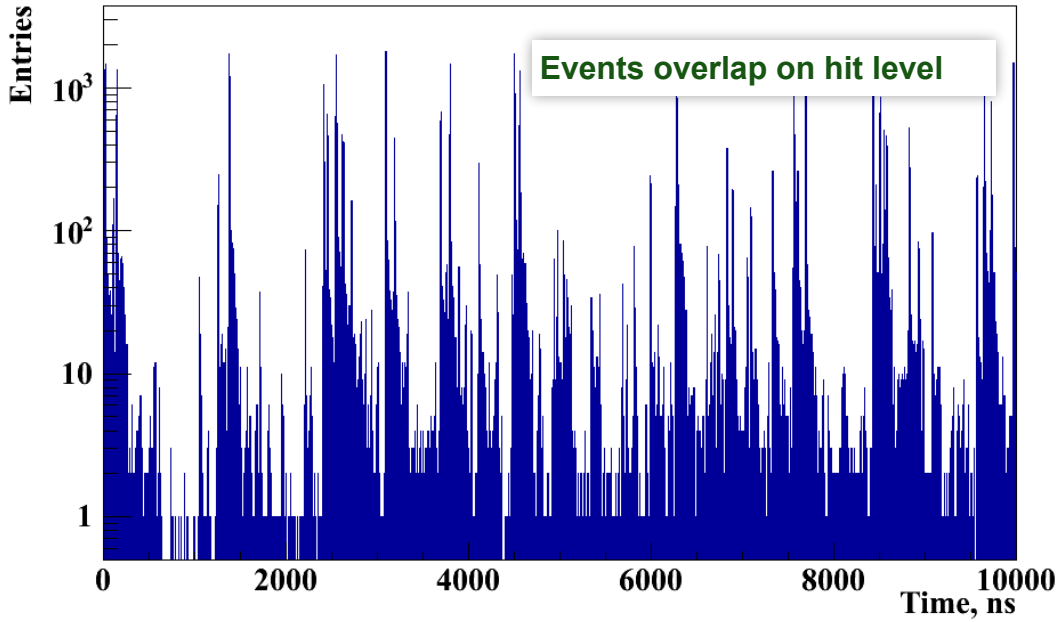
Time-based Reconstruction in CBM



- Interaction rate up to 10 MHz
- free-streaming data
- self-triggered front-end electronics
- no simple hardware trigger

Events overlap

Hit time measurement in STS at interaction rate 10 MHz



- Time-slice rather than event-based reconstruction
- Time-based tracking: 4D measurements (x, y, z, t)

4D tracking

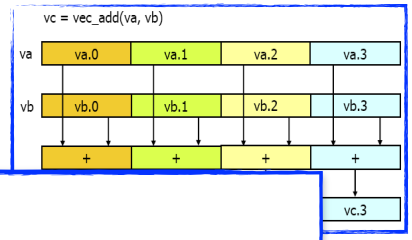
Track state vector:

$(x, y, t_x, t_y, q/p) \rightarrow (x, y, t_x, t_y, q/p, t)$

position | slope | momentum | +time

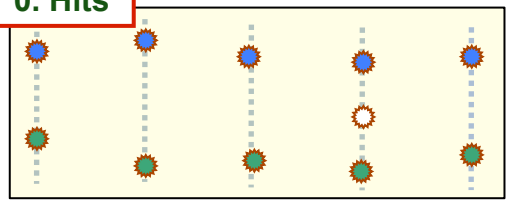
No a-priori association of signals to physical events!
Correct procedure of event building from time-slices is crucial for right physics interpretation.

Parallel within Time-slice CA Track Finder

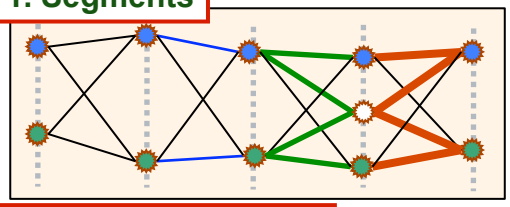


Header files
Vc

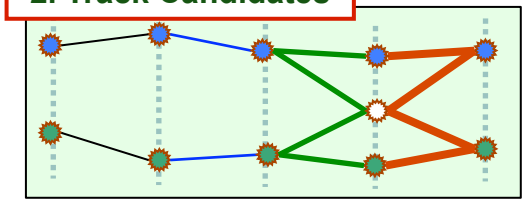
0. Hits



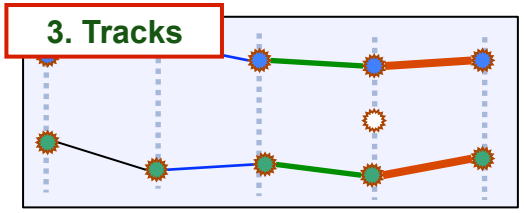
1. Segments



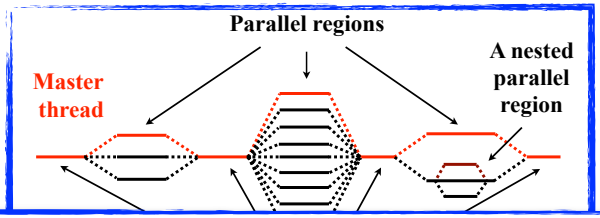
2. Track Candidates



3. Tracks



OMP
Pthreads



OMP
Pthreads

thread 1 | thread … | thread n

n threads

0. Hits

hit portion | hit portion | hit portion | hit portion

1. Segments

triplets | triplets | triplets | triplets

2. Track Candidates

candidates | candidates | candidates | candidates

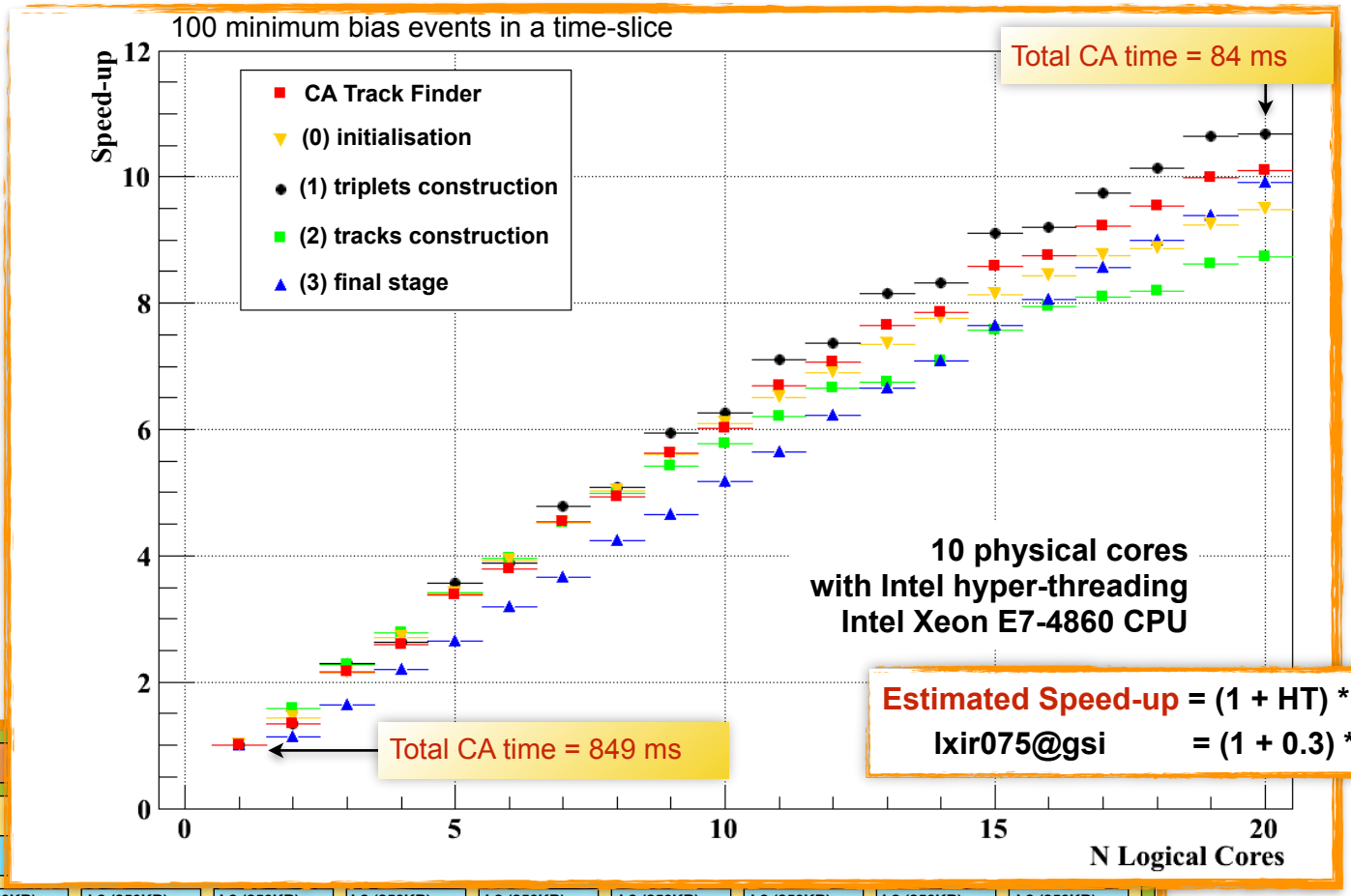
3. Tracks

synchronisation | synchronisation

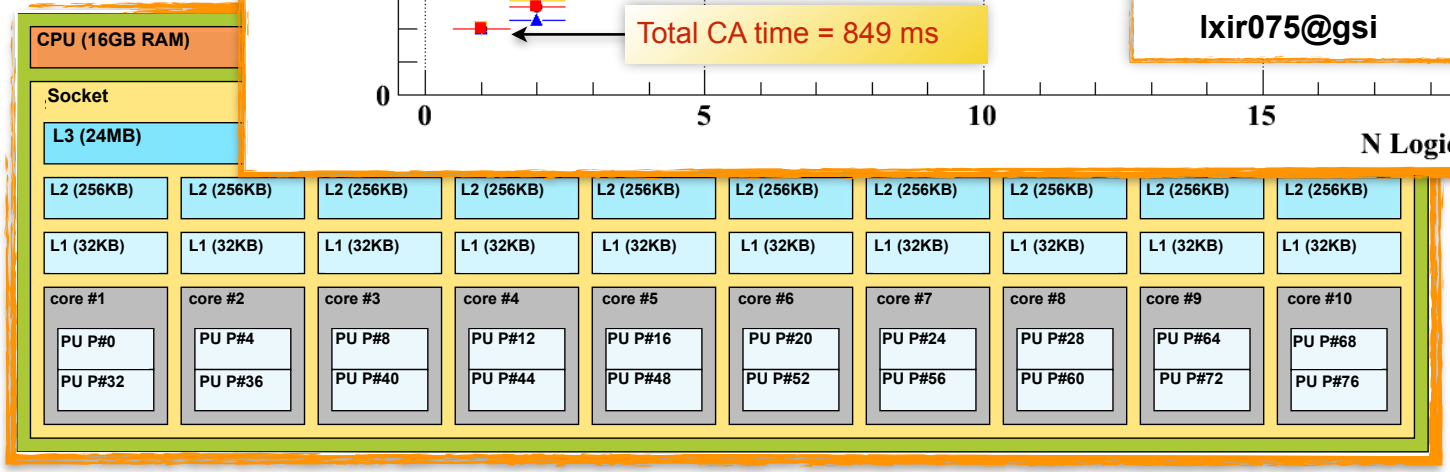
tracks ↔ tracks ↔ tracks ↔ tracks

Each stage of the algorithm is both vectorized (using SIMD instructions) and parallelized (between CPU cores).

CA Track Finder Scalability



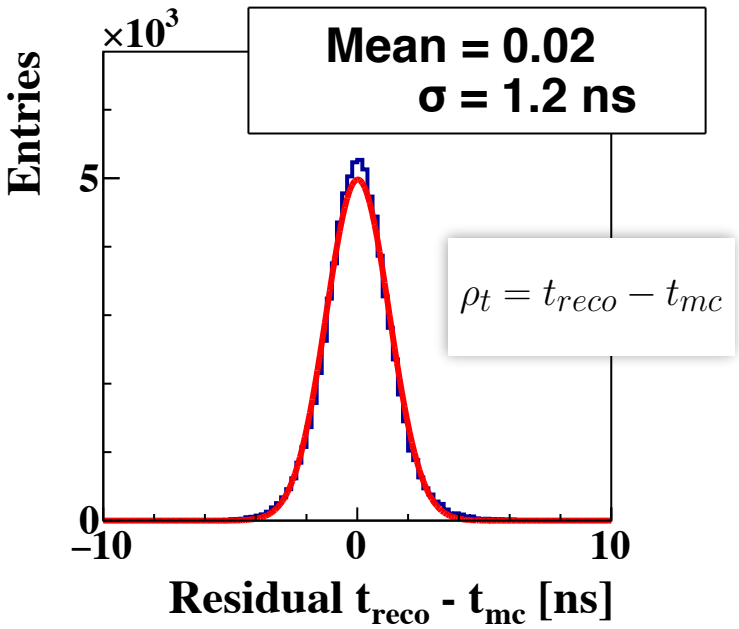
Estimated Speed-up = (1 + HT) * N cores
lxir075@gsi = (1 + 0.3) * 10 = 13

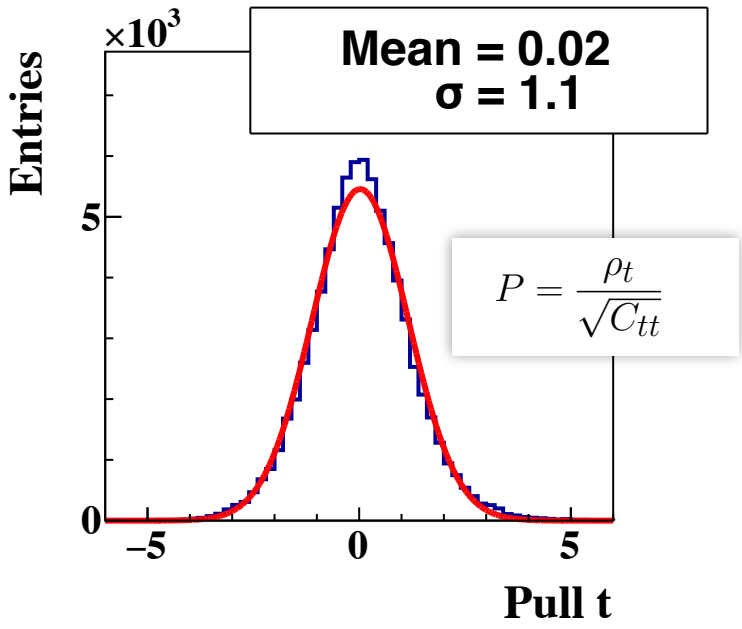


The CA Track Finder shows strong scalability on many-core machines.
Speed-up factor 10,1 Theoretically estimated factor: 13

4D Track Fit

Track state vector:
$(x, y, t_x, t_y, q/p) \rightarrow (x, y, t_x, t_y, q/p, t)$





Time is added to the track fit:

- The vector of parameters and its covariance matrix are extended.
- Propagation and Kalman filter are extended.
- Fit shows correct results: high resolution and pulls close to 1.

Time coordinate has been fully added to the fitting procedure.

4D Track Finder in CBMROOT

4D Track Finder Modifications:

- Triplets from the hits with the same time measurement within 3σ of detector precision
- Fast access to the hits: data re-organisation 2D grid to 3D grid structure
- 4D Fit: time has been fully added to the fitting procedure

3D CA time/event = **8.2** ms

comparable speed (standalone version)

4D CA time/event = **8.5** ms

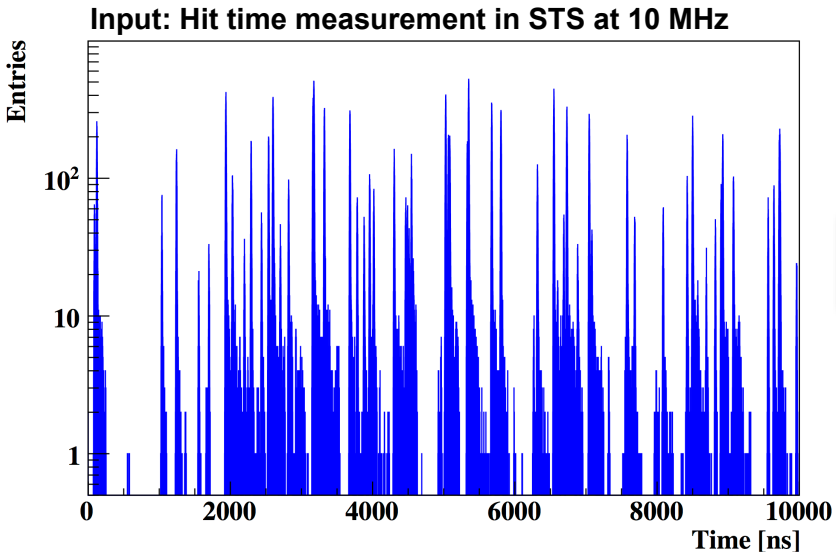
100 AuAu minimum bias events at 10 AGeV

Efficiency, %	3D	4D 0.1MHz	4D 1MHz	4D 10MHz
All tracks	92.5 %	93.8 %	93.5 %	91.7 %
Primary high-p	98.3 %	98.1 %	97.9 %	96.2 %
Primary low-p	93.9 %	95.4 %	95.5 %	94.3 %
Secondary high-p	90.8 %	94.6 %	93.5 %	90.2 %
Secondary low-p	62.2 %	68.5 %	67.6 %	64.3 %
Clone level	0.6 %	0.6 %	0.6 %	0.6 %
Ghost level	1.8 %	0.6 %	0.6 %	0.6 %
True hits per track	92%	93 %	93 %	93%
Hits per MC track	7.0	7.0	6.97	6.70

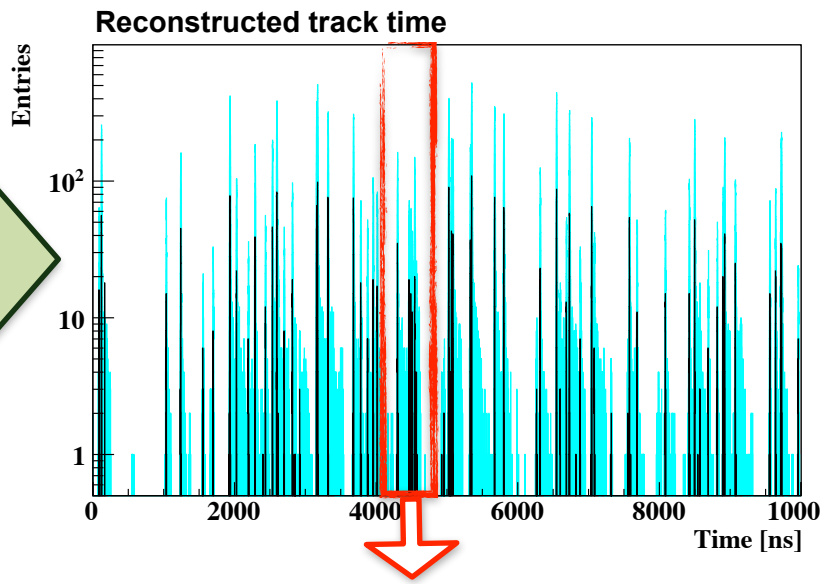
Timeslices from CBMROOT, time-based digitisation, cluster and hit finder

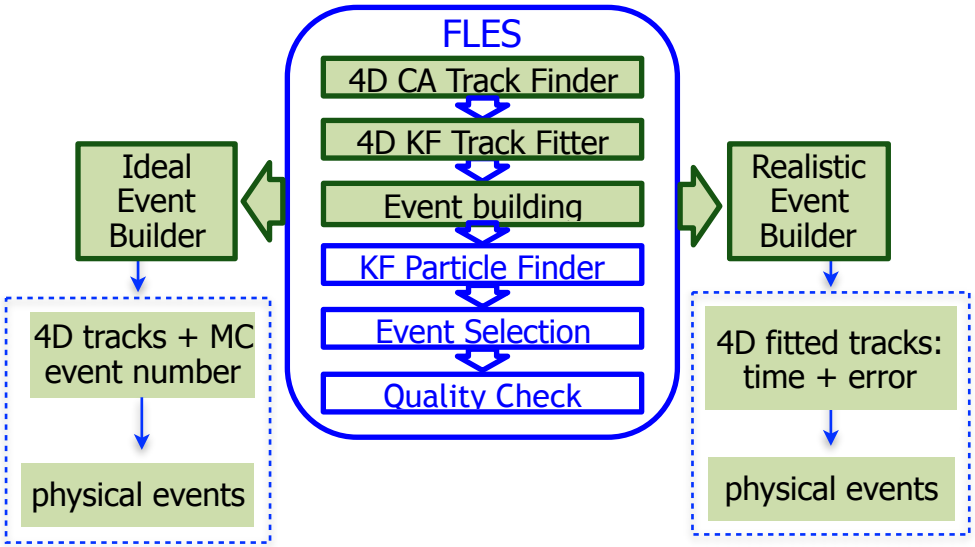
Time-based tracking performance comparable with event-by-event.

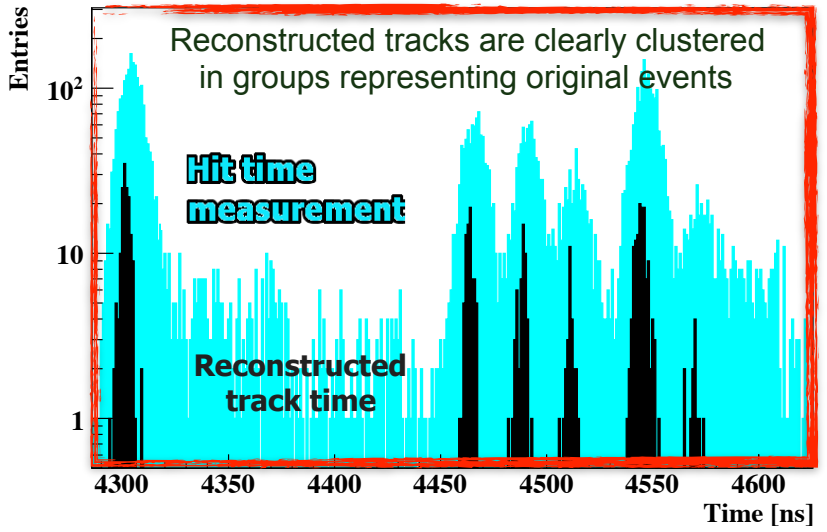
4D Reconstruction Chain



Track Finder

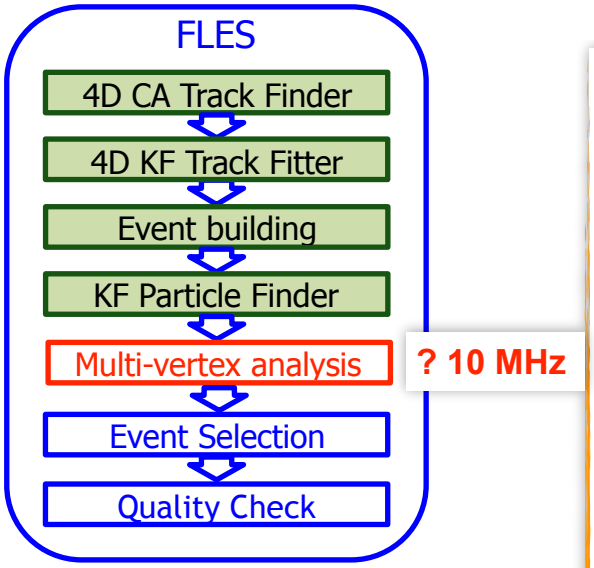






Event building as a part of the CBM reconstruction chain.

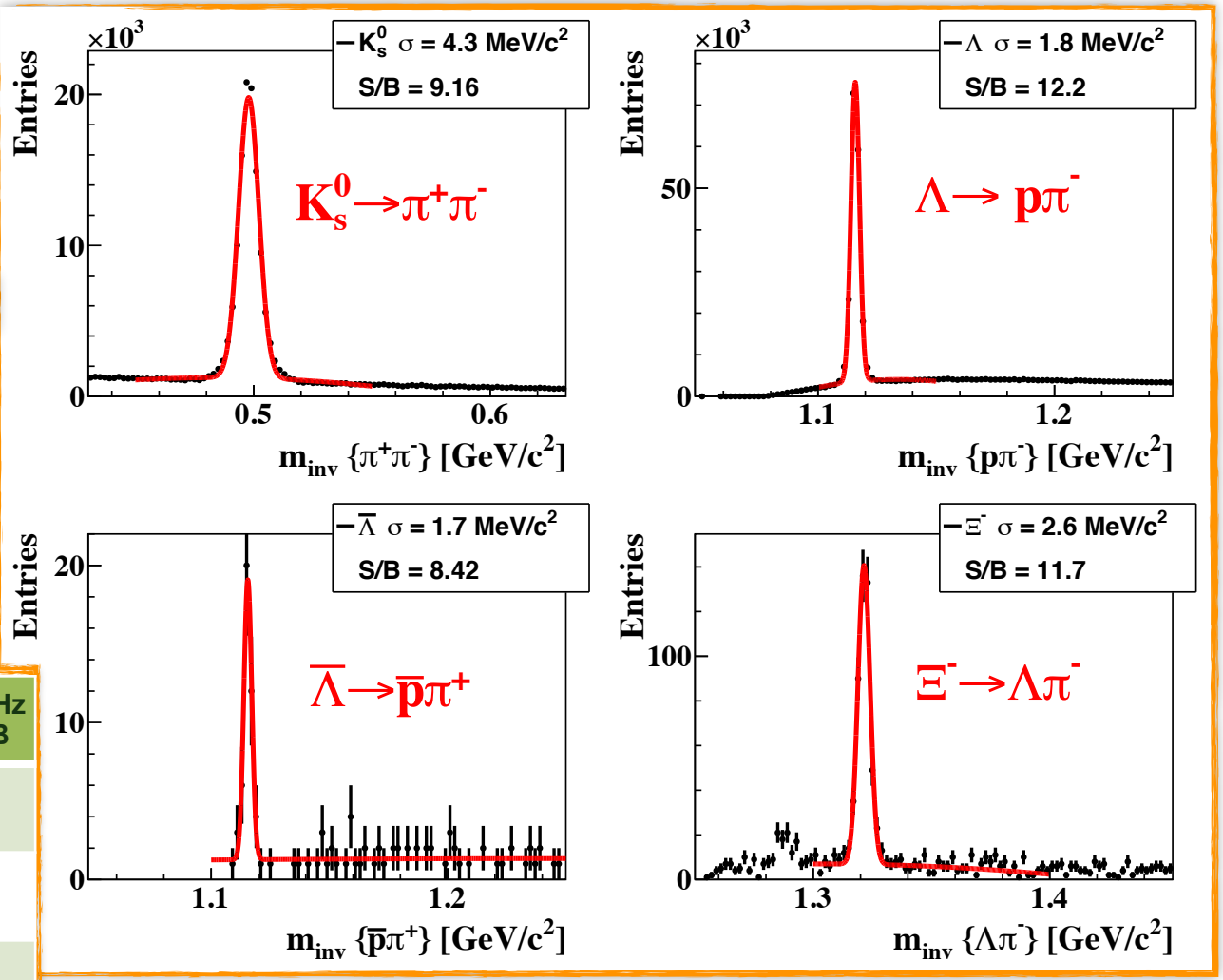
4D Reconstruction of Short-lived Particles



Extreme case of 10 MHz interaction rate requires further input from fast detectors (ToF) and multi-primary vertex analysis

Particle /Case	3D	4D 10 MHz Ideal EB	4D 10 MHz Real EB
K^0_s	22.9%	21.2%	21.2%
Λ	21.9%	19.8%	19.6%
Ξ^-	7.8%	6.3%	6.3%

300k mbias AuAu 10 AGeV events at 10 MHz, KF Particle Finder, ideal PID, realistic event builder



4D track finder provides high track quality sufficient for short-lived particle reconstruction.

Summary

Parallel track finder algorithm capable of time-slice based reconstruction have been developed.

- The **parallel CA track finder shows linear scalability** with speed-up factor of 10.1 out of 13 theoretically estimated factor within the Intel Xeon E7-4860 CPU.

- **4D CA track finder** allows to reconstruct time-slices with **speed and efficiency comparable to event-based approach.**

- The first version of **event builder algorithm** based on 4D CA track finder has been implemented. It allows to perform physics analysis with KF Particle Finder.

Future Plans

- Multiple primary vertices analysis.

- Add TOF information.

- Add realistic PID.