Parallel 4-Dimensional Cellular Automaton Track Finder for the CBM Experiment

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Reconstruction Challenge in CBM

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

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

Events overlap on hit level

Correct procedure of event building from time-slices is crucial for right physics interpretation
First Level Event Selection Package (FLES)

Event building as a part of FLES package
Cellular Automaton (CA) Track Finder

1. Segments
   - Build short track segments - triplets.
2. Neighbors & Counters
   - Mark possible neighbours while building triplets.
3. Track Candidates
   - Connect according to the track model, estimate a possible position on a track.
   - Tree structures appear, collect segments into track candidates.
4. Tracks
   - Select the best track candidates.

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

Perfect for many-core CPU/GPU!
How to use time information in tracking?

- Triplets are built from the hits with the same time measurement within 3 $\sigma$ of detector precision.
- Fast access to the hits is provided by time-based structure: hits are sorted by time and space coordinates and stored into the time-based grid.

**Variable time step of grid: 4D tracking in a 3D-style approach**
4D CA Track Finder Scalability

Parallel implementation with OpenMP and Pthreads

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

Parallelism inside a time-slice, 100 mBio events in a time-slice, Intel Xeon E7-4860

Total time = 849 ms

Total time = 84 ms

Parallel implementation with OpenMP and Pthreads

- CA Track Finder
- Initialisation
- Triplets Construction
- Tracks Construction
- Final Stage

Speed-up factor 10.1  Theoretically achievable factor: 13
### 4D Track Finder in CBMroot Framework

| Efficiency, % | 3D    | 4D    | CBMROOT |
|---------------|-------|-------|---------|
| All tracks    | 92.1  | 92.2  | 91.3    |
| Primary high-p| 97.9  | 97.9  | 99.1    |
| Primary low-p | 93.6  | 93.5  | 93.6    |
| Secondary high-p | 92.0  | 92.0  | 88.9    |
| Secondary low-p | 65.7  | 65.9  | 56.8    |
| Clone level   | 2.8   | 3.1   | 3.7     |
| Ghost level   | 4.9   | 4.2   | 1.9     |

Time/event/core | 11.7 ms | 13.6 ms | 17.3 ms

CBMroot revision 8357 (Nov 2014)  
3D, 4D: AuAu 25 AGeV mbias events at 10MHz  
CBMROOT: AuAu 10 AGeV mbias events at 10MHz

Time-based tracking performance comparable with event-by-event
Reconstructed tracks are clearly clustered in groups representing original events.
Event Building at IR = 10 MHz

Reconstructed tracks are grouped in events using histogramming:
- all tracks are filled in a time histogram with bin width of 1 ns
- neighbouring not empty bins are called an event
- gap of a 4 empty bins is a sign for event end

- 70 reco events are reconstructed one-to-one, 7 reco events are merged together.
- Primary tracks can be separated using primary vertex information.
- Search of only one primary vertex per event using KF Particle Finder package is currently implemented.
- Multi-vertex reconstruction is in progress.

7% of events are merged to be studied with multi-vertex analysis
Event building is a necessary part of FLES package
• Time-based 4D track finder allows to reconstruct time-slices with speed and efficiency comparable to event-based approach
• 4D track finder is parallel with speed-up 10.1 out of 13 theoretically achievable within the Intel Xeon E7-4860 CPU
• A first version of event building was implemented based on the 4D tracking.

Future Plans
• Multiple primary vertices analysis
• Physics analysis