Event building for free-streaming readout in the CBM experiment

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Abstract. CBM is the first experiment gaining advantage of free-streaming triggerless readout system. All readout channels of the detector going to work in self triggered mode. Dedicated methods are developed to extract individual events (collisions) from continuous information stream rejecting noise. Efficiency of the methods depends on projectile energy, masses of colliding nucleons, interaction and accelerator frequencies. Quality control of the algorithms and comparison of the methods require special efforts.

1. Introduction
CBM [1] is the first large scale high energy experiment going to work in free-streaming readout mode. There will be no hardware trigger in the CBM. All readout electronics channels will work in self triggering mode and provide information about actuation time. All information obtained from the detector in a given time period is called time-slice. The duration of a time-slice will be more than 1\,\mu s and may differ for various colliding system and energies. The time-slices should be self-sufficient. The reconstruction of a time-slices should be performed on a computing cluster. The computation unit for reconstruction is not fixed at the moment. It can be a processor core, which is standard for modern high energy physics, processor or entire computer. The last two options reduces memory and network bandwidth demands but requires a highly efficient parallelized reconstruction algorithms. After the reconstruction interesting data will be saved to the disk. Complex conditions (such as event topology, track reconstruction and identification quality, etc) can be easily used for data selection. Utilization of complex conditions for data selection is extremely important for various rare physical processes, such as reconstruction of D-mesons (for example $D^0 \to K^- \pi^+$ decay), multistrange baryons etc.

In physical analysis one usually interested in all tracks and vertexes produced by an individual collision of ions but not by several collisions in a given period of time. So individual collisions (events) should be reconstructed (build) from a time-slice data using dedicated event building algorithms. Applicability of a given event building algorithm depends on mass of colliding nucleus, projectile energy and interaction rate. The collision association is required only for physical objects such as tracks, vertexes but not for individual activated electronic channels (digis) or intermediate reconstruction objects like clusters.

There are two approaches of event building at CBM:

- event building at the level of individual activated electronic channels (digis);
Figure 1. Digi dynamics in time for minimum bias gold ions collisions at 10 AGeV modeled with UrQMD at 1 MHz interaction rate. The peaks at 3460, 3650 and 4100 ns correspond to a heavy ions collisions. The peak near 3710 ns is generated by delta electrons born after the collision.

- event building at tracks level.

Both approaches will be described in a next two sections. Only tracking information from STS detector is used for simplicity in further studies. Background from delta-electrons born in the target by passing through beam ions is not modeled in CBM, only particles produced in a heavy nucleus collisions are simulated.

2. Event building at digi level

Event building at digi level implies that no reconstruction is performed at time-slice level. So only very simple variables, like digi dynamics in time and number/position of hit detectors, can be used for event building. All acquired digis are associated with events. Well established and tested in many experiments event based reconstruction methods can be used afterwards. But event building at digi level should have low performance at high interaction rate. In CBM this method is considered as a backup solution and should work up to 1 MHz interaction rate.

The most difficult situation for event building at digi level happens with collisions of gold ions at highest possible energy in CBM (10 AGeV for SIS100). From the one side the event builder should be able to find a very peripheral collisions which produce very low number of tracks in detector acceptance and, therefore, digis. From the other side, it should reject digis produced by delta electrons spiralling in the tracking system. Figure 1 illustrates problem in more detail. The number of received digis in a 4 ns bins for minimum bias gold-gold collisions at 10 AGeV with 1 MHz collision rate is shown on figure 1 as a function of time. Several clear peaks are visible. The peaks near 3460, 3650 and 4100 ns correspond to a heavy ions collisions as it known from Monte Carlo true information. While peak near 3710 ns is generated by delta electrons born by particles passing through detector material.

The event formation is started if number of digits in 2 ns time period exceeds a given threshold \( T \) and all eight STS stations produced at least a single digi in the same period of time. All digis
Figure 2. (Top) Fraction of good (red), bad (blue) and empty (green) events as a function of the threshold of the simple event building algorithm. (Bottom) Probability of event finding for event, which contain at least 5 reconstructable tracks in ideal case, as a function of the same threshold.

produced from staring 2 ns before found time period to 2 ns after it associated with the event. The algorithm does not look for events in subsequent 6 ns after event construction to reduce production of empty events, containing only digis from delta electrons. The exact threshold value was tuned for 10 AGeV minimum bias gold-gold collisions at 1 MHz interaction rate (see figure 2).

For robust reconstruction of primary vertex of heavy ions collision one requires at least five tracks in the detector acceptance. The probability of successful finding of such event as a function of the threshold is shown on the bottom plot of figure 2. All found events can be either “good” or “bad”. The event is “good” if

- it contains no long (>5 STS hits) track form other events;
- it contains at least five tracks in the detector acceptance in event based case;
- the difference between number of found tracks with event based reconstruction is less than
The fraction of “good” and “bad” events as a function of threshold $T$ is shown on a top plot of figure 2. The fraction of build events which contain no found tracks is shown in the same plot separately as “empty” events. Finally $T = 500$ digis for 2 ns was taken as the threshold value. The found threshold ensures 90% event finding efficiency for events of interest. 90% of found events are “good” events.

Presented study describes a method of threshold value determination for any colliding system. The success of the method for minimum bias gold-gold collisions at 1 MHz interaction rate ensures a correct results for lighter colliding systems and/or lower interaction rates and provides a backup solution for event finding at low interaction rates for the CBM detector.

3. Event building at track level

Event building at track level should work for highest CBM interaction rate of 10 MHz but requires development of track finding and track fitting methods for tracks and vertexes reconstruction from time-slice data. Such a development requires much more resources and time than event building at digi level.

The first step in track reconstruction for time-slice data is modification of track finding algorithms. The track finding [2] starts from space points provided by the reconstruction algorithms of STS detector. The space points are combined into triplets. The triplets with common space points are combined into track candidates. The last should pass a dedicated selection to became a found tracks. The time of space points is not used in event-by-event reconstruction.

The quality of track reconstruction for time-slices will be significantly degraded because of pile up if no time information is used. The only modification of track finding is in the triplet formation algorithm. The time of the space points forming a triplet should differ in a range of $3.5\sigma$, where $\sigma = 5$ ns and much more then a time-of-flight between stations of STS detector.

First implementation of event building at track level is based on histogramming method. All reconstructed tracks are put into histogram with bin width of 1 ns. Neighbor not empty bins are called an event. Four empty bins in the histogram is required to separate events. The implementation does not demonstrate enough performance gold-gold collisions at 10 MHz interaction rate: 10% of found events contains two or more primary vertexes.

The performance of an event building at track level will be enhanced

- with implementation of primary multi-vertex reconstruction in CBM software;
- with explicit introduction of time into state vector in the track fitting procedure:

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

This will increase accuracy of track time reconstruction.

4. Conclusions

Developed event building algorithms at digi level demonstrates adequate performance and should be generalized to treat information not only form tracker but form other CBM subdetectors. The current development of event building algorithms at track based level does not allow to use them at full interaction rate of CBM. However, first version of the algorithm is implemented and will be enhanced with multi-vertex reconstruction and introduction of time into state vector in track fitting procedure.

References

[1] The CBM Collaboration 2005 *Tech. Stat. Rep.* 1
[2] Akishina V and Kisel I 2015 *IEEE Trans. Nucl. Sci.* 62(6) 3172