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Time-based Reconstruction of Free-streaming Data in CBM

Valentina Akishina[1,3,⋆], *Ivan* Kisel[1,2,3], *Iouri* Vassiliev[3], and *Maksym* Zyzak[3]

[1] *Goethe-Universität Frankfurt, Frankfurt am Main, Germany*
[2] *Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany*
[3] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany*

Abstract. Traditional latency-limited trigger architectures typical for conventional experiments are inapplicable for the CBM experiment. Instead, CBM will ship and collect time-stamped data into a readout buffer in a form of a time-slice of a certain length and deliver it to a large computer farm, where online event reconstruction and selection will be performed. Grouping measurements into physical collisions must be performed in software and requires reconstruction not only in space, but also in time, the so-called 4-dimensional track reconstruction and event building. The tracks, reconstructed with 4D Cellular Automaton track finder, are combined into event-corresponding clusters according to the estimated time in the target position and the errors, obtained with the Kalman Filter method. The reconstructed events are given as inputs to the KF Particle Finder package for short-lived particle reconstruction. The results of time-based reconstruction of simulated collisions in CBM are presented and discussed in details.

1 Introduction

The physics program of the CBM experiment [1] requires studying the multiplicity, distribution in phase space and collective effects of all interesting particles, including very rare short-lived particles. In order to collect enough statistics, the fixed-target experiment will be run at extreme interaction rates of up to 10 MHz. The complicated topology of the trigger decays and observables does not allow to build a hardware trigger based on raw detector data. Thus, the experiment will operate with free-streaming data and self-triggered front-end electronics. Within such a complicated operation scenario detector measurements corresponding to particles produced in different collisions cannot be separated based on their time information in a simple way.

The experiment will ship and collect time-stamped data into a readout buffer in the form of a time-slice of a certain length. The collisions will be resolved in the online mode by the First Level Event Selection (FLES) package [2] during the reconstruction of tracks and short-lived particles. The reconstruction algorithms have been developed to operate with the time-slices taking into account the time information. The time-based algorithms demonstrate performance similar to the conventional event-by-event mode.

⋆e-mail: V.Akishina@gsi.de

Table 1. Track reconstruction efficiency performance for one hundred minimum bias AuAu collisions at 25 *A*GeV in the cases of event-by-event reconstruction and time-slice-based reconstruction at 0.1 MHz, 1 MHz and 10 MHz interaction rates, presented for different track categories.

Track category, %	E-by-E	10^5Hz	10^6Hz	10^7Hz
All tracks	92.1	92.6	92.6	92.2
Primary high-p	97.9	98.2	98.2	97.9
Secondary high-p	92.0	92.7	92.7	92.0
Clone level	2.8	0.3	0.3	3.1
Ghost level	4.9	3.5	3.5	4.2

2 Reconstruction of particle trajectories

The track finder algorithm used to reconstruct charged particle trajectories in the tracking detectors of CBM is based on the Cellular Automaton method (CA) [3, 4]. Since the experiment is designed to work with free-streaming data, the algorithm takes as input hits from a time-slice, which include time and spacial measurements. During the first stage the CA track finder combines the hits, delivered by the reconstruction algorithms of the main tracking detector of CBM – the Silicon Tracking System (STS), into combinations of three hits on adjacent detector stations, so-called triplets. The Kalman Filter method [5] allows to estimate the momentum of such track segments before constructing the whole track.

In order to take into account detector inefficiency, a missing hit in one station is tolerated for a reconstructed track. The triplets are combined into track candidates. The track candidates which pass through a special selection procedure according to their χ^2 and length are taken for reconstructed tracks. To get a faster and more efficient algorithm, the track reconstruction is done in several iterations. In the first iteration only high-momentum primary tracks are reconstructed, in the second one – low-momentum primary tracks, and then – all other tracks. After each iteration the used hits are removed from further consideration, since it significantly reduces the combinatorics. This is particularly important for later iterations when searching for low-momenta and secondary tracks [6].

The resulting track reconstruction efficiency for different track sets and ratios of clones and ghost tracks for the event-by-event analysis as well as for the 4D CA track finder in case of reconstructing time-slices, produced out of one hundred AuAu minimum bias event at 25 *A*GeV, are presented in table 1. For evaluation purposes the particle is called reconstructable if it has crossed at least 4 stations of the STS detector. A reconstructed track is assigned to a simulated particle, if at least 70% of its hits have been caused by the same particle. If a certain particle is assigned to more than one track, such additionally reconstructed track candidates are regarded as clones. If a track was not assigned to any particle according to the 70% criterion it is called a ghost. The tests have been performed on an Intel Xeon E7-4860 CPU server.

The inclusion of the time and optimization of the event-based track finder algorithm into the time-based reconstruction have made it possible to achieve an efficiency performance comparable to that of the event-by-event analysis. Moreover, the track reconstruction efficiency has been improved after taking into account the STS time measurement even for the case of the highest interaction rate scenario of CBM. It can be explained by the presence of slow particles, which create random combinations of hits and cannot be rejected in the absence of time information.

The CA track finder is both vectorized (using SIMD instructions) and parallelized (between CPU cores with the help of OpenMP interface). The algorithm shows strong scalability on many-core systems. The speed-up factor of 10.6 has been achieved on an Intel Xeon E7-4860 CPU with 10 hyper-threaded physical cores [7].

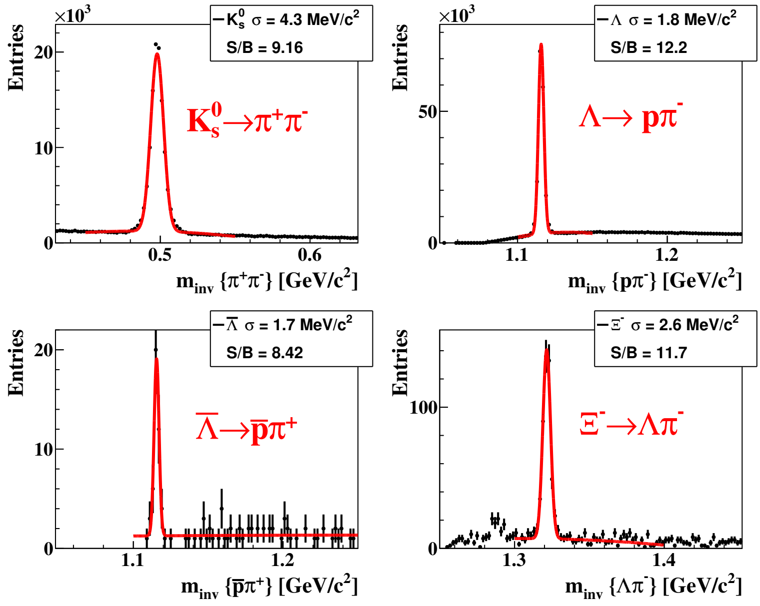

Figure 1. Mass spectra of strange particles reconstructed in 300k AuAu minimum bias UrQMD events at 10 *A*GeV energy and 10 MHz interaction rate using event builder and KF Particle Finder. For particle identification of daughter products the Monte Carlo information was used as the first step.

3 Event building

The highest interaction rate scenario of CBM requires a special event building procedure at the track level, which will allow to resolve information on different collisions from each other and deliver isolated events for the physics analysis. The input for the event building algorithm are tracks, reconstructed with the CA track finder, spacial and time parameters of which are estimated with the Kalman Filter procedure. The first implementation of the event builder [6] algorithm splits the reconstructed tracks into event-corresponding groups based on the information of fitted time parameter in the region of primary vertex and the estimated errors, obtained from the track fit [7].

The results of the event building have shown, that 83% of events were reconstructed without event merging and 17% of events were merged into double event clusters. The avoidance of event splitting was achieved. The presence of event merging shows that the time information in the STS alone is not enough to resolve all events from each other at the interaction rate of 10 MHz and the remaining events are to be resolved later via searching for several vertices with the help of event topology.

The currently implemented procedure is based on the information from the STS detector alone. The addition of information obtained by the Time-of-Flight (ToF) detector, the time resolution of which is by several orders of magnitude better, is expected to drastically improve the ability to resolve different events, containing ToF time information, from each other [6].

4 Reconstruction of short-lived particles in time-slices

Tracks grouped into events are provided as an input for the next step of the reconstruction chain — reconstruction of short-lived particles. The properties of short-lived particles contain a large part of the CBM physics. These particles cannot be registered directly by the detector system, but only reconstructed from their decay products. Short-lived particles were reconstructed by the KF Particle Finder package [2, 8] in each event, provided by the event builder algorithm. As the first approach, one primary vertex in each reconstructed event was assumed. Further, the multi-primary-vertex analysis will be implemented, that is required to improve event separation and signal to background ratio of the reconstructed particles for the extreme case of 10 MHz interaction rate.

Tests of 300k AuAu minimum bias UrQMD [9, 10] events at 10 *A*GeV energy were simulated assuming the interaction rate of 10 MHz. The simulated events were reconstructed using the event builder and the KF Particle Finder package. As the first step, the long-lived daughter particles were identified by the Monte Carlo information. The reconstructed mass spectra of the most abundant strange particles and anti-particles are shown in figure 1. Further addition of the time information from the fast ToF detector and implementation of the multi-primary-vertex analysis will allow to bring the reconstruction performance even closer to the results of event-by-event analysis.

Conclusions

The first version of the FLES reconstruction chain for the CBM experiment has been developed. It contains stages of track finding, track fitting, event building, short-lived particle finding, and event selection. The package allows to reconstruct free-streaming data collected by the detector and obtain reconstructed particles from individual collisions in the end. The resulting efficiencies and combinatorial background are similar to the event-based analysis, showing high values for the signal to background ratio for short-lived particle reconstruction even for the 10 MHz interaction rate.

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