Event Reconstruction in the CBM Experiment

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CBM Experiment

The CBM Collaboration [1] builds a dedicated heavy-ion experiment to investigate the properties of highly compressed baryonic matter as it is produced in nucleus-nucleus collisions at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.

The scientific goal of the research program of the CBM experiment is to explore the phase diagram of strongly interacting matter in the region of highest baryon densities. This approach is complementary to the activities at RHIC (Brookhaven) and ALICE (CERN-LHC) which concentrate on the region of high temperatures and very low net baryon densities.

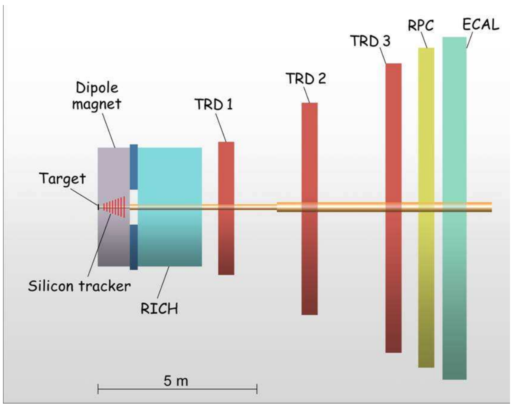

Figure 1: Geometry of the CBM experiment

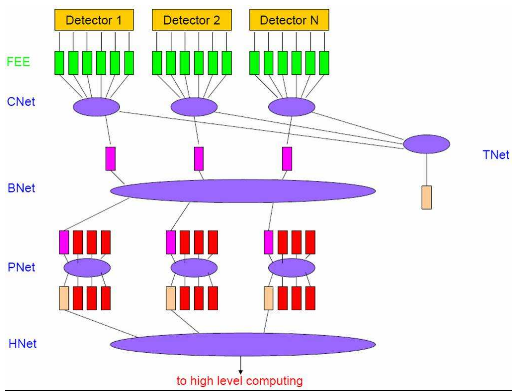

Figure 2: DAQ architecture

The experimental setup has to fulfil the following requirements: identification of electrons which requires a pion suppression factor of the order of 10^5; identification of hadrons with large acceptance; determination of the primary and secondary vertices (accuracy $\approx 30\ \mu$m); high granularity of the detectors; fast detector response and read-out; very small detector dead time; high-speed trigger and data acquisition; radiation hard detectors and electronics; tolerance towards delta-electrons. Figure 1 depicts the present layout of the CBM experimental setup.

Inside the dipole magnet gap are the target and a 7 plane Silicon Tracking System (STS) consisting of pixel and strip detectors. The Ring Imaging Cherenkov detector (RICH) has to detect electrons. The Transition Radiation Detector (TRD) arrays measure electrons with momentum above 1 GeV. The TOF stop detector consists of Resistive Plate Chambers (RPC). The Electromagnetic Calorimeter (ECAL) measures electrons, photons and muons. The CBM setup is optimized for heavy-ion collisions in the beam energy range from about 8 to 45 AGeV.

The concept of DAQ architecture [2, 3] adopted for CBM will use self-triggered front-end electronics, where each particle hit is autonomously detected and the measured hit parameters are stored with precise timestamps in large buffer pools. The event building, done by evaluating the time correlation of hits, and the selection of interesting events is then performed by processing resources accessing these buffers via a high speed network fabric. The large size of the buffer pool ensures that the essential performance factor is the total computational throughput rather than decision latency. Since we avoid dedicated trigger data-paths, all detectors can contribute to event selection decisions at all levels, yielding the required flexibility to cope with different operation modes.

In this approach we have no physical trigger signal, which prompts a data acquisition system to read a selected event and transport it to further processing or storage. The role of the data acquisition system is to transport data from the front-end to processing resources and finally to archival storage. The event selection is done in several layers of processing resources, reminiscent of the trigger level hierarchy in conventional systems.

A logical data flow diagram is shown in Fig. 2, indicating the data sources and processing elements as boxes and every form of interconnection networks as ovals. The main components are: front-end electronics (FEE); clock and time distribution (TNet); concentrator net (CNet); active buffers; build network (BNet); processing resources; processing network (PNet) and high-level network (HNet).

The first level of event selection processing has to handle the full event rate, and depending how many detector subsystems are involved in the decision, a substantial fraction of the total data volume. A very rough estimate shows, that processing a data flow on the scale of a TByte/sec is likely to require a computational bandwidth on the scale of 10^{15} operations/sec.

Typical central Au+Au collision in the CBM experiment will produce up to 700 tracks in the inner tracker. Large track multiplicities together with the presence of a non-homogeneous magnetic field make the reconstruction of events complicated. Therefore the collaboration performs an extensive analysis of different track recognition methods in order to better understand the geometry of the detector and to investigate specific features of accepted events [1].

Here we describe a reconstruction procedure based on a cellular automaton method.

Cellular Automaton based track finding

The cellular automaton method [4, 5] creates short track segments (tracklets) in neighbouring detector planes and strings them into tracks (Figure 3).

Being essentially local and parallel cellular automata avoid exhaustive combinatorial searches, even when implemented on conventional computers. Since cellular automata operate with highly structured information, the amount of data to be processed in the course of the track search is significantly reduced. Usually cellular automata employ a very simple track model which leads to utmost computational simplicity and a fast algorithm.

By definition, a reconstructed track is assigned to a generated particle, if at least 70% of its hits have been caused by this particle. A generated particle is regarded as found, if it has been assigned to at least one reconstructed track. If the particle is found more than once, all additionally reconstructed tracks are regarded as clones. A reconstructed track is called a ghost, if it is not assigned to any generated particle (70% criteria).

Efficiency of track reconstruction for particles detected in at least four stations is presented in Figure 4. Tracks of high momentum particles are reconstructed very well

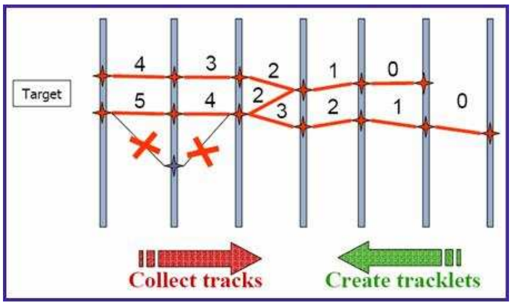

Figure 3: A simple illustration of the cellular automaton algorithm

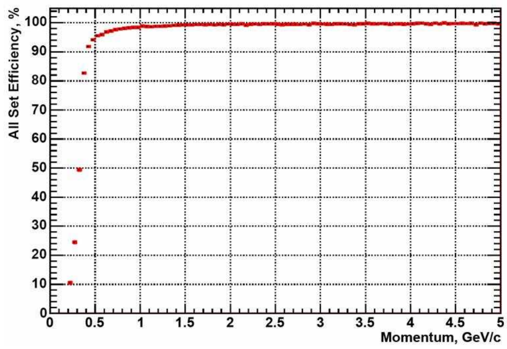

Figure 4: Track reconstruction efficiency as a function of momentum

with efficiencies of 99.45%, while multiple scattering in detector material leads to a lower reconstruction efficiency of 89.46% for slow particles. The reconstruction efficiency for fast primary tracks with momentum higher than 1 GeV/c is almost 100%, while the efficiency of all fast tracks is slightly lower because of the presence of secondary tracks, originating far downstream from the target region. Total efficiency for all tracks with a large fraction of soft secondary tracks is 96.98%. Clone rate is not a problem for the algorithm (0.01%). Ghost level is at 0.61%.

Track and vertex fitting

Track and vertex fittings have been done using the Kalman filter based procedures [1, 6]. Propagation of tracks in non-homogeneous magnetic field is based on a specially developed analytic formula [7, 8].

Mean relative momentum resolution for all tracks is 0.69%. Secondary tracks from D^0 decay being longer have slightly better momentum resolution of 0.67%. After the primary vertex is reconstructed, tracks identified as primary can be refitted with an additional constraint to the primary vertex position. This improves their average track momentum resolution to 0.63%.

The primary vertex was determined from all tracks reconstructed in the STS excluding those which formed well detached vertices like K^0_S and Λ decays. The Kalman filter based algorithm reconstructs the primary vertex with the accuracy of 4 μm for the longitudinal and better than 1 μm for transversal components of the primary vertex position.

Precision of the secondary vertex parameters obtained in the geometrical vertex fit can be improved by taking into account several assumptions on tracks associated to the vertex. Two types of constraints have been included into the secondary vertex fit: a mass constraint and a topological constraint. The mass constraint is usually applied in the case of one or several combinations of particles in the vertex are known to originate from a narrow width mass state. The topological constraint is used to point a mother particle to the (already reconstructed) primary vertex. Final accuracy is 44.4 μm for the longitudinal and 1.7 μm for transversal components of the secondary vertex position for D^0 decay.

Standalone RICH ring finder

Standalone finding of rings in RICH detector is based on the elastic neural net [9, 10]. The method does not require any prior track information and can be used for triggering. Application of the method to the RICH detector of the CBM experiment shows an efficiency of 94.3% and high speed (5.4 ms per event with about 1400 hits in the RICH detector). Because of its computational simplicity and high speed, the algorithm is considered to be further implemented in hardware which can increase the speed by another few orders of magnitude.

Summary

The track finding algorithm based on the cellular automaton method is developed for the reconstruction of tracks in the inner tracker of the CBM experiment. Comprehensive tests of the algorithm have shown high reconstruction efficiency and low ghost rate. The algorithm has a reasonable behaviour of the CPU time consumption and robustness with respect to large track densities. The algorithm is intrinsically parallel and therefore suitable for implementation on multiprocessor systems like the STI cell processor. It is also possible to implement the most time consuming combinatorial part of the algorithm in hardware, for instance FPGAs, thus speeding the algorithm up to a few orders of magnitude. Having experience in the HERA-B and LHCb experiments we expect that the cellular automaton algorithm will work reliably with more realistic simulated and real data of the CBM experiment.

Track and vertex fitting procedures are based on the Kalman filter. Propagation of tracks in non-homogeneous magnetic field is based on a specially developed analytic formula.

The standalone RICH ring finder is based on the elastic net method. It has demonstrated a good ring finding efficiency and a high speed.

References

[1] Akishin P.G., Akishina E.P., Baginyan S.A., Ivanov V.V., Ivanov Valery V., Kostenko B.F., Litvinenko E.I., Ososkov G.A., Raportirenko A.M., Soloviev A.G., Zrelov P.V., Uzhinsky V.V., Compressed Baryonic Matter Experiment. Technical Status Report, GSI, Darmstadt, 2005 (http://www.gsi.de/onTEAM/dokumente/public/DOC-2005-Feb-447_e.html).

[2] I. Kisel, "Fast tracking in the CBM experiment", 11th Workshop on Electronics for LHC and future Experiments (LECC2005), 12–16 September, 2005, Heidelberg, Germany.

[3] D. Atanasov, A. Walsch, I. Kisel and V. Lindenstruth, "A megahertz farm with a data flow control system", 11th Workshop on Electronics for LHC and future Experiments (LECC2005), 12–16 September, 2005, Heidelberg, Germany.

[4] I. Kisel, "Tracking in the CBM experiment", Workshop on Tracking in High Multiplicity Environments (TIME05), 03–07 October, 2005, Zurich, Switzerland (to appear in Nucl. Instr. and Meth. A).

[5] R. Arnold, C. Augier, A.M. Bakalyarov, . . . , I.Kisel et al. (NEMO Collaboration), "Technical design and performance of the NEMO 3 detector", Nucl. Instr. and Meth. A 536 (2005) 79–122.

[6] S. Gorbunov, I. Kisel and Iou. Vassiliev, "Analysis of D^0 meson detection in Au+Au collisions at 25 AGeV", CBM note CBM-PHYS-note-2005-001, 23 June 2005.

[7] S. Gorbunov and I. Kisel, "An analytic formula for track extrapolation in an inhomogeneous magnetic field", CBM note CBM-SOFT-note-2005-001, 18 March 2005.

[8] S. Gorbunov and I. Kisel, "Analytic formula for track extrapolation in non-homogeneous magnetic field", X International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT 2005), May 22–27, 2005, DESY, Zeuthen, Germany (to appear in Nucl. Instr. and Meth. A).

[9] S. Gorbunov and I. Kisel, "Elastic net for standalone RICH ring finding", CBM note CBM-SOFT-note-2005-002, 22 September 2005.

[10] S. Gorbunov and I. Kisel, "Elastic net for standalone RICH ring finding", X International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT 2005), May 22–27, 2005, DESY, Zeuthen, Germany (to appear in Nucl. Instr. and Meth. A).