EPJ Web of Conferences **108**, 02001 (2016)
DOI: 10.1051/epjconf/201610802001

Online Selection of $J/\psi \to \mu^+\mu^-$ Decays in the CBM Experiment

T.O. Ablyazimov[1,a] and V.V. Ivanov[1,2,b]

[1] *Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna, 141980, Russia*
[2] *National Research Nuclear University "MEPhI", Moscow, Russia*

Abstract. The Compressed Baryonic Matter (CBM) experimental setup is currently being constructed at the Facility for Antiproton and Ion Research (FAIR) acceleration complex at GSI (Darmstadt, Germany) by an international collaboration that includes a team from JINR. One of the main goals of this experiment is to study the charmonium production in high-energy nuclear collisions. The experiment will operate at extreme interaction rates of up to 10 MHz. The expected dataflow rate will be of the order of 1 TB/s, making it impossible to store all the raw data from detectors in long-term buffers. It will demand the selection of $J/\psi \to \mu^+\mu^-$ decays in real-time. This paper presents criteria for the fast and effective selection of signal events by using exclusively data on charged muon hits collected in the Muon Chamber (MUCH) coordinate stations and describes the software implementing these criteria. The possibility of this software to solve the problem of the online selection $J/\psi \to \mu^+\mu^-$ decays is proven.

1 Introduction

To make the CBM possible the FAIR acceleration complex for antiprotons and heavy ions is under construction at present at GSI, Darmstadt. The physics program of CBM aims at thoroughly exploring the properties of the superdense baryonic matter produced in nuclear collisions at beam energies up to 45 GeV per nucleon [1].

The J/ψ meson detection is one of the key tasks in the CBM experiment. J/ψ mesons are detected indirectly by observing the detritus of their decays. The CBM experimental setup for detecting dimuon decays is shown in figure 1. Accelerated ions collide with the nuclei of a fixed target enclosed by a superconducting dipole magnet. The magnet also covers the Silicon Tracking System (STS) which is the key detector of the CBM experiment. The Muon Chamber (MUCH), the Transition Radiation Detector (TRD) and the Time of Flight (TOF) detector are aligned downstream the ion beam. The muon chamber consists of 6 stations each of which contains 3 detecting layers (we assumed all of them are pixel detectors in our simulations). Each station is shielded by an iron absorber at the left of it (see figure 2).

As only one of approximately 10^7 events produces J/ψ decaying to a $\mu^+\mu^-$ pair which goes to the MUCH acceptance, the nuclear collision intensity must be up to 10^7 per second. The DAQ recording

[a] e-mail: abl@jinr.ru
[b] e-mail: ivanov@jinr.ru

ability is expected to be in the range of 10 kHz – 25 kHz [2, 3] which implies that a trigger of signal events with a suppression ratio of 400 – 1000 is needed. The detection and reconstruction of $J/\psi \to \mu^+\mu^-$ decays (signal events) must be performed online, which demands very fast methods of their selection.

The paper presents the software developed by the authors which, as we believe, solves the problem of the online $J/\psi \to \mu^+\mu^-$ events selection. This software uses simple and efficient criteria for identifying and selecting decays using information about the trajectories of charged particles detected by the MUCH coordinate stations. These trajectories are reconstructed by a fast algorithm based on the cellular automaton model [4].

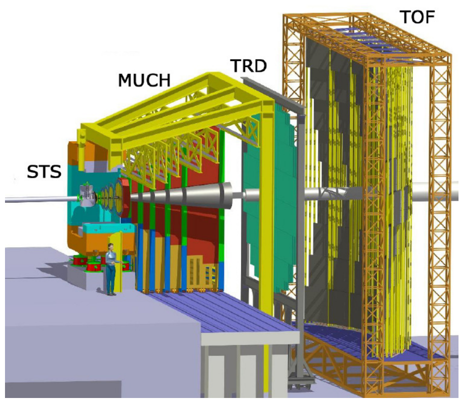

Figure 1. CBM experimental setup for studying dimuon decays

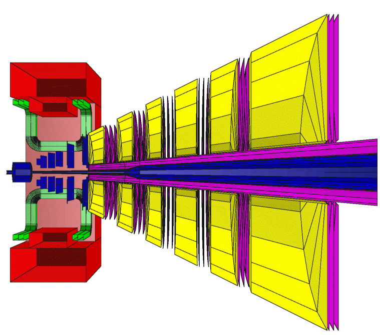

Figure 2. The muon chamber (MUCH) in cross-section

2 Track search algorithm

Because of the high momenta of the muons produced in J/ψ decays and the low values of the magnetic field strength inside MUCH [5], we neglect by the influence of the magnetic field and use a linear model of the particle trajectories. We also take into account only those tracks which have hits in all of the MUCH stations to make sure we deal only with high momenta tracks. The algorithm is subdivided into three stages described in the subsections below.

2.1 Midpoint calculation

Each of the coordinate stations in the MUCH detector includes three detecting layers placed parallel to each other at a distance of 10 cm. Considering the registration efficiency of the detecting planes for charged particles (more than 90%), muons must hit at least two (out of three) planes of the station. While forming the track segments, the algorithm uses hits from the midplanes of the MUCH stations. Let us call them “midpoints”. The “calculation of midpoints” consists of two parts: lost signal hits restoration and background hits removing. The first one is done by synthesizing hits which are midpoints between pairs of hits on the outermost planes of the station in case when it is possible to draw a straight line close to both these hits passing through the target center but not having close hits on the midplane. The mentioned line could be a possible trajectory of a signal muon. The second part of the midpoint calculation consists in removing a hit on the midplane if there are not hits near the straight line drawn through the hit and target center on at least one of the outermost planes.

2.2 Segment building

The cells of our cellular automaton are line segments connecting hits of midplanes of two adjacent stations. As the decay muons vertices lie in the vicinity of the target center and we do not take into account any deterministic force affecting the particles, all the reconstructed trajectories must be close to straight lines originating from the target center. As a consequence for each pair of stations we create segment sets containing only segments the inclinations of which do not deviate much from the line drawn between the segment right end and the target center as shown in figure 3. The limits for such deviations are different for each pair of adjacent stations and determined by Monte Carlo simulation in advance (see figure 4).

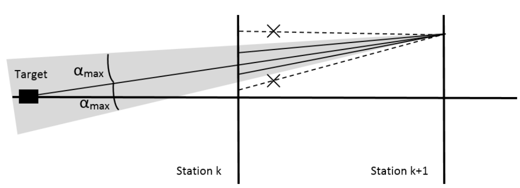

Figure 3. Formation of segments

2.3 Segment binding

Now we consider all pairs of consecutive segments for which the right end hit of one is at the same time the left end of another. If the angle between the segments of a given pair does not exceed the limits determined by Monte Carlo simulation, the segments are considered as neighbours and “bound” (see figure 5 and figure 6).

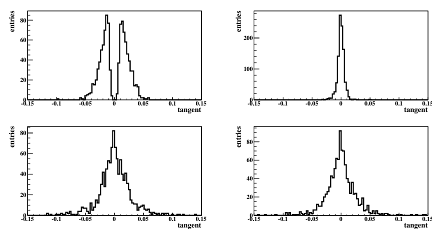

Figure 4. Segment inclination deviations. In XOZ plane on the left and in YOZ on the right. For the first station on top and for the last below

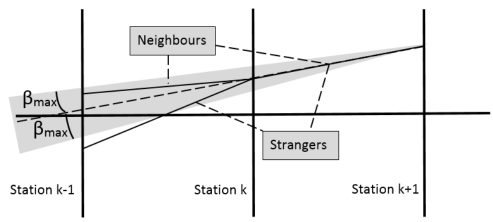

Figure 5. Segment binding

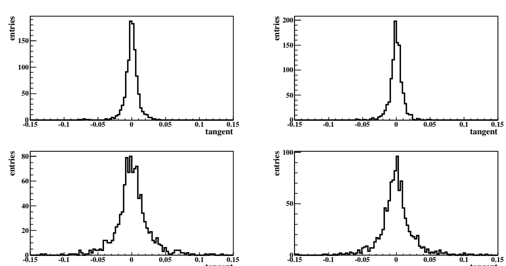

Figure 6. Angles between neighbour segments. In XOZ plane on the left and in YOZ on the right. For the second station on top and for the station before the last below

2.4 Choosing the best track candidates

On the last stage of the algorithm, segment chains (track candidates) are built. To form a chain, we start from a segment having right its end on the rightmost MUCH station and put it to the chain. For this moment this segment is the chain end. Then a chain duplicate is created for each (left) neighbour segment of the current chain end by joining the piece of chain built up to this moment with this neighbour. This process continues until the chain end has neighbours. All the chains which end on segments having their left hits on the first MUCH station are considered "valid". Then, among all the valid chains starting from a given rightmost segment the one having the lowest χ^2 is chosen.

3 Acceleration of the track finder algorithm

We made substantial efforts to accelerate the track finder implementation, which included vectorization and parallelization using the OpenMP framework. The Figure 7 demonstrates how the track finder runtime depends on the number of parallel threads on a Linux workstation with 48 logical (24 physical) Intel Xeon cores.

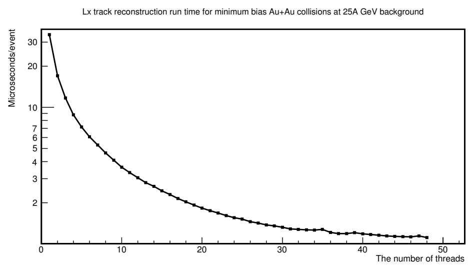

Figure 7. Track finder runtime per one event as function of the number of threads

4 Event selection criteria

It turned out possible to create an efficient trigger for $J/\psi \rightarrow \mu^+\mu^-$ events using exclusively the information on tracks reconstructed in MUCH. We imposed an obvious condition for an event to have at least two reconstructed tracks to be marked as signal. Then we demand that there is a pair of reconstructed tracks satisfying the following two conditions in each signal event: 1) the tracks belong to particles with different electric charge signs and 2) the angle between the tracks exceeds a certain value. The following two subsections give the motivation for this.

4.1 Particle electric charge sign identification

The electric charge sign of a muon can be reconstructed with a sufficient degree of confidence using the geometrical properties of its trajectory. This evaluation is done by considering the sign of the difference of the angles of the projections to the XOZ-plane of the first segment of a track and the line drawn through the target center and the right end of the segment. The charge sign of the particle equals this sign. See the upper-left graph in figure 4 and figure 8 for visualisation of the idea. About 93% of reconstructed tracks have been attributed with the right sign in simulation.

4.2 Screening by distance

Because of the large Q value of the J/ψ decay, its daughter muons have, on the average, a large momentum difference in the lab frame. As a consequence of this, they intersect the first MUCH station at a sufficient distance. Our investigations indicate that they cross the first station at distances exceeding 50 cm. In figure 9 the histograms for distances between tracks for signal pairs and for arbitrarily chosen pairs are depicted.

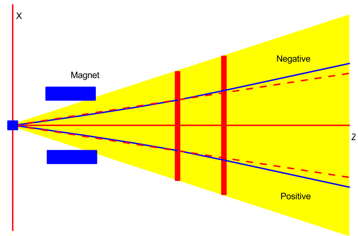

Figure 8. Particle electric charge sign evaluation

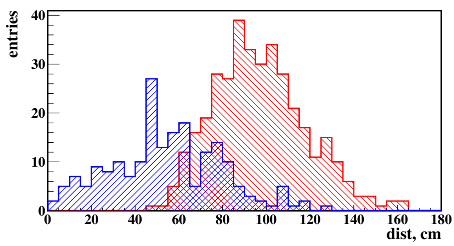

Figure 9. Screening by distance

5 Results and conclusion

We assesed our implementation with respect to two quality figures: its ability to discover signal events and its ability to suppress background. The simulated data for evaluation of the first mentioned value were prepared by combining outputs of two generators: PLUTO (for signal muon pairs) and UrQMD simulating central Au+Au collisions at 25A GeV (for the background). The efficiency of the signal recovery was found to be 87.5%. The background suppression was assessed by inputting data generated by UrQMD for minimum bias Au+Au collisions at 25A GeV. A suppression ratio of 1600-1700 was obtained, which is substantially larger than the minimally needed value for this property indicated in the introduction.

It can be seen that to achieve the needed performance of handling 10^7 events per second we need only dozens of conventional workstations built on Xeon cores. The resulting output data stream would have an intensity suitable for storing it by the DAQ of CBM. So we conclude that our approach solves the task of online selection of J/ψ decays in the CBM experiment.

References

[1] The CBM Collaboration, "Compressed baryonic matter experiment" Technical Status Report (GSI, Darmstadt), p. 6 (2005)
[2] A. Kiseleva et al., CBM Progress Report 2008, (GSI, Darmstadt), p. 69 (2009)
[3] P. P. Bhaduri et al., CBM Progress Report 2008, (GSI, Darmstadt), p. 70 (2009)
[4] T. O. Ablyazimov, V. V. Ivanov, CBM Progress Report 2014, (GSI, Darmstadt), p. 117 (2015)
[5] The CBM Collaboration, Technical Design Report for the Superconduction Dipole Magnet, (GSI, Darmstadt), p. 15 (2013)