DEVELOPMENT OF ONLINE EVENT DISPLAY USING THE ATLAS TDAQ SOFTWARE FOR THE NICA EXPERIMENTS

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One of the problems to be solved in high energy physics experiments on particle collisions or fixed target experiments is online visual presentation of events during an experiment run. The article describes implementation of this task by developed Online Event Display, for the running BM@N (Baryonic Matter at Nuclotron) experiment and the future MPD (Multi-Purpose Detector) experiment at the Nuclotron-based Ion Collider facility (NICA) being under construction at the Joint Institute for Nuclear Research in Dubna. The implemented event display, designed for use in offline and online modes, with its options and features as well as integration with software environments of the experiments are considered. The examples of graphical representation of simulated and reconstructed points and particle tracks with BM@N and MPD geometries are shown for collisions at different energies. The article includes a brief description of the ATLAS TDAQ system. One of the main aspects of the development shown in the paper is integration of the ATLAS TDAQ components to transfer raw event data for visualization of the NICA experiments in Online Event Display.

Keywords: visualization of event data, online event display, physics data processing, experiment monitoring, NICA collider, BM@N, MPD, ATLAS TDAQ.

1. Introduction

The study of extremely hot and dense nuclear matter is an urgent problem of modern physics. It is of special interest in connection with the possibility of discovering a new state of matter – the quark-gluon plasma, which is the subject of research of modern high energy physics experiments, and which existence is predicted by the modern theory of strong interactions – quantum chromodynamics. Studying the properties of the quark-gluon plasma, the most fundamental problems of modern physics can be investigated: the nuclear equation-of-state (EOS) at high densities, manifestations of possible deconfinement and chiral symmetry restoration, the properties of the mixed quark-hadron phase, phase transitions and the presence of the critical end-point on the phase diagram.

According to the research program on heavy-ion collisions at the Nuclotron of the Joint Institute for Nuclear Research (JINR), the Nuclotron-based ion collider facility is being constructed as an ion accelerator complex for the range of collision energy $\sqrt{S_{NN}}$ from 4 to 11 GeV for gold ions. Figure 1 presents the design of the NICA facility.

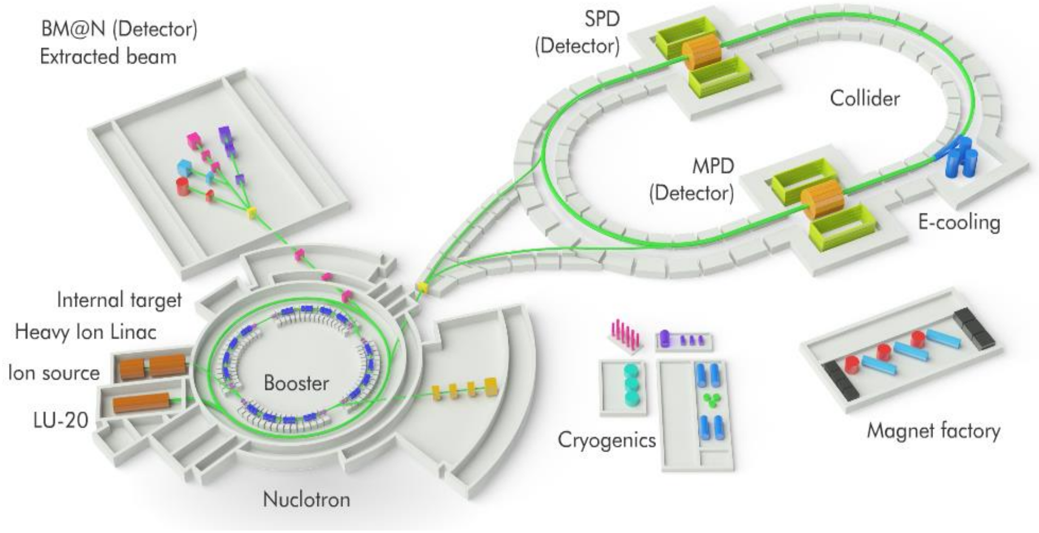

Figure 1. The NICA facility

A new generation of the experiments for heavy-ion physics is expected to turn on in the nearest years at NICA. The BM@N [1] is a fixed target experiment at extracted Nuclotron beam of the Laboratory of high energy physics (LHEP JINR) to study collisions of elementary particles and ions with a fixed target with the energy up to 6 GeV per nucleon. The BM@N facility is one of the main elements of the first stage of the NICA project. It is proposed to study the elementary reactions and cold nuclear matter, the properties of dense baryonic matter in heavy ion collisions with a fixed target, in-medium effects, hypermatter production, strangeness and hadron femtoscopy. Since 2015, four technical sessions of the BM@N experiment with deuteron and carbon beams collided with various targets, such as carbon, copper and lead, at the energies 3.5 – 5 GeV per nucleon have been conducted.

Two interaction points are foreseen at the storage rings of the NICA facility for two detectors. The MultiPurpose Detector [2] located at one of the points is optimized for a comprehensive study of the properties of hot and dense nuclear matter in heavy-ion collisions over a wide range of atomic masses and search for the critical point of the phase transition to the quark–gluon plasma.

In the central collisions of heavy gold ions, which are supposed to be used in the experiments, at NICA energies, high multiplicity can be reached. The detectors should identify the particles produced in the collisions with high efficiency and estimate their parameters with high precision for the full study of hot matter that is why the detectors are constructed as the set of different types of sub-detectors. In addition to the large multiplicity of events, it is necessary to take into account high event rate at the NICA complex. With such a large data stream, a system for visual monitoring of selective events registered by detectors should be used on a computer farm operating online.

2. Event Display in modern high energy physics experiments

Visual representation of events is an important part in modern high energy physics experiments. Event displays find their use in online and offline monitoring and viewing of detector operation, as aids in physics analysis, and in production of displays showcasing physics results. A fast, efficient and comprehensive monitoring system is a vital part of major high energy physics experiments on particle collisions, such as, for example, CMS, ALICE and ATLAS.

The CMS event display is called Fireworks [3] which core is built on the top of the Event Data Model and the light version of the framework FWLite. Event Visualization Environment (EVE) of the ROOT environment is used to manage 3D and 2D views, selection, and user-interaction with the graphics windows. The event display is especially crucial for data quality control system, filtering of the immense amounts of complex event data from the CMS detector and preparing clear and flexible views of the salient features to the shift crews in online mode and offline users of the CMS collaboration to process and analyze the obtained data. This software provides a visual interpretation of the CMS data on an event-by-event basis and helps in tuning and timing-in the sub-detectors.

ALICE Event Visualization Environment (AliEVE) [4] is used in the ALICE experiment. It is based on the ROOT GUI environment and its graphical classes for work with two- and three-dimensional geometric objects, and OpenGL library. The collaboration group developed base classes to provide graphical representation and management of visualization objects for high energy physics included in the ROOT environment as a new package – EVE for applying it in other experiments. The AliEVE system is used in the ALICE experiment for event visualization in offline mode and for high-level trigger frameworks of the running experiment. It graphically represents clusters, tracks and the simplified detector geometry. The event display plays an important role in detector calibration, occupancy and noise-levels estimation in the ALICE experiment.

Own event visualization system named Atlantis has been developed for the ATLAS experiment. Atlantis [5] is a stand-alone graphical application written in Java, which aims to provide easy, fast, error free visual investigation and physical understanding of complicated events. This visualization system employs a variety of 2D event data-oriented projections with simplified geometry of the ATLAS detector, event detail and summary information to allow users to understand and quickly visually estimate the parameters of particle collision events, as well as to check the correctness of reconstruction steps and links between physical objects, e.g. corresponding hits to particle tracks.

3. Development of Event Display for NICA experiments

Offline and online event display can be distinguished. Offline Event Display is used at the design stage of detectors and offline data processing to perform the following tasks: model and reconstruction algorithm checking and debugging, analysis of algorithms for event data processing by experts; data reconstruction and physics analysis visualization for a better understanding of the detectors and event structure by users; demonstration and presentation of works of the experiment.

To support the BM@N and MPD experiments of the NICA complex, the BmnRoot and MpdRoot software are developed, respectively. The frameworks serve for event simulation, reconstruction of experimental or simulated data and following physics analysis of particle collisions in the MPD and collisions with a fixed target registered by the BM@N facility. The developed event display is the same part of the BmnRoot and MpdRoot environments. It became integrated into the experiment software to combine different stages of event processing with a graphical representation of these events to evaluate and check the correctness of reconstruction and physics analysis algorithms.

To display detector geometries and events of the NICA experiments, high-level graphics package EVE of the ROOT environment was chosen. ROOT graphical classes and the OpenGL library are used at the EVE package to quickly display three-dimensional objects and their two-dimensional projections. The EVE classes were developed primarily for the creation and management of event objects in high energy physics experiments, such as: raw data, hits, clusters, points and particle tracks.

The implemented event display shows the detector geometries and events from different projections and views. A user of the system can select a convenient graphical representation, events to display, primary or secondary particles with definite PDG codes or in a given energy range, objects to be presented on the screen, configure parameters of physical objects, set light sources, desired colors and many other visualization settings. Three methods of geometry coloring were released in the developed visualization system: default by ROOT, hierarchical and pre-selected for detectors. The event display offers full interactivity, supporting zooming, on-line rotations and picking of objects.

Visualization of simulated events proceeds the following way. The data obtained by the event generators (e.g. UrQMD, QGSM) are passed to simulation macro transferring particles through the detectors by particle transport packages. In addition, the designed detector geometries in ASCII or ROOT formats are converted by the simulation macro into a corresponding hierarchy of the ROOT geometric shapes, transformation matrices and other graphics information that are stored in the ROOT file with simulated data. After the simulation has been completed, the result file contains both Monte-Carlo (MC) data and detector geometry. The next step is the reconstruction of particle data, tracks and other parameters that are written to the ROOT DST file. Event display macro was implemented to run the visualization system and control graphical representation of the following objects on the screen: detector geometry, MC tracks and their points, as well as reconstructed hits and tracks. The event display macro uses the file with simulated data and detector geometry and the DST file with reconstructed data for graphical representation of the NICA experiments via the EVE package.

In order to visualize events of the experiments, event display classes were developed for management of different physics objects, such as hits, simulated and reconstructed points and particle tracks, calorimeter towers, and their graphical representation. Figure 2 presents an example of the BM@N event display with the simulated (UrQMD generator) and reconstructed track points of the central gold ion collision with a gold target at the energy 4 GeV per nucleon.

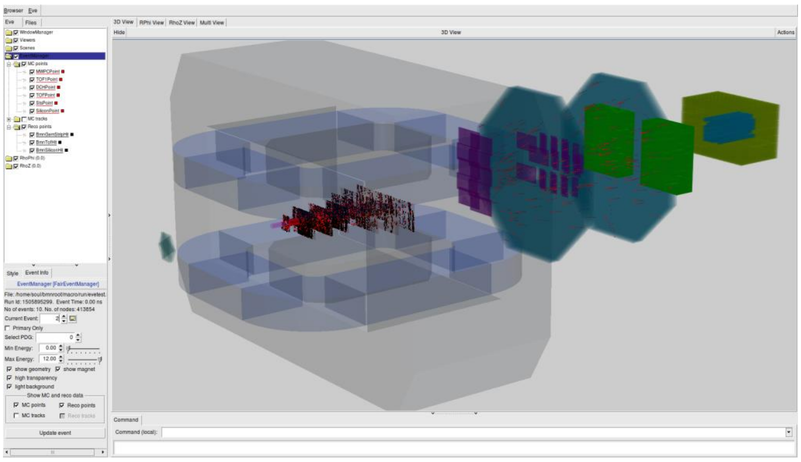

Figure 2. The BM@N Event Display with MC points and reconstructed points

Figure 3 shows the event display view for the MPD experiment with the reconstructed data, such as TPC Kalman tracks, for simulated Au-Au collision at 7 GeV. Tracks of different particles are highlighted in different colors for clarity.

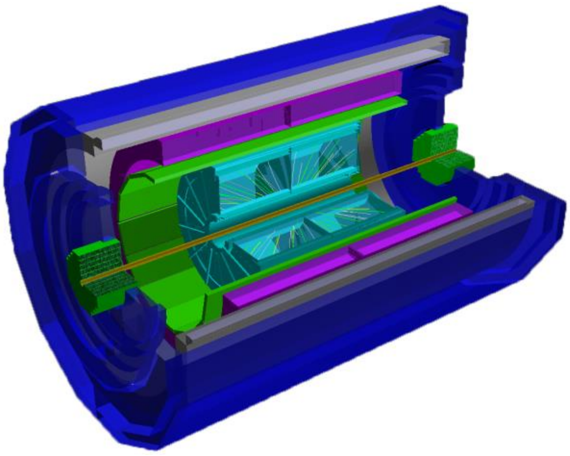

Figure 3. The MPD event display with reconstructed TPC Kalman tracks

The event display in offline mode can visualize experimental data: hits and tracks reconstructed from raw format by the digitizer (translating the interactions with detectors into the digits being saved in the ROOT file) and following clustering and tracking procedures. The event display gets detector geometries from the Unified Database [6] which stores geometries for each run.

4. Online Event Display using ATLAS TDAQ software

The data stream from the detector electronics up to the data storage of the NICA experiment is organized as a sequential data-driven pipeline. The Trigger System performs online event selection in the experiment. Upon reception of a sequence of trigger signals requesting the data collection, the selected elements of the detectors generate data fragments that are transferred via optical links and collected into events by Event Builder. Then the events are sent to the Transient Data Storage – a low-latency and high-throughput distributed storage system, where the events are used in online operator systems, such as checking raw data quality, online histogramming and online event display (Event Monitor).

The Online Event Display is used for online visual presentation of selective events during the experiment run as a monitoring system, and for visual control and debugging of current events at the run stage. Visual monitoring of physical processes and data is very important in this case, for example, for visual estimation of the multiplicity of current events which depends on the impact parameter of the particles. The developed system should be able to quickly show hits, particle tracks and geometry of detectors that register these particles.

To transfer raw event data outside Data Acquisition system to machine with the Online Event Display and powerful graphics card for visualization of the NICA experiments, components of the ATLAS Trigger and Data Acquisition (TDAQ) [7] system were chosen. It consists of the High-Level Trigger, which performs event selection and reduces data, and the DAQ system, which transports event data from the detector readout to the HLT system and selected events to the mass storage.

The ATLAS Online Software [8] is a sub-system of the TDAQ, which encompasses the software to configure, control and monitor the TDAQ and detectors. It consists of three main parts: Control, Databases and Monitoring frameworks. The Monitoring framework includes components to provide software for the detector monitoring and event display implementation, such as Event Monitor Service (EMS) to transport samples of events, and Online Histogramming Service to exchange histograms. In addition to the transportation of the monitoring data, the Monitoring framework provides the possibility to transport the monitoring data requests from consumers to providers.

In the large distributed system, it must be possible to transport the monitoring information from the point, where it is produced to the point where it can be processed or visualized. The developed Online Event Display uses the following components of the TDAQ framework: basic communication service which is common for all online services – Inter Process Communication (IPC), and Event Monitoring Service. The IPC built on the top of the CORBA broker defines a high-level

API for the distributed object implementation and remote object location. The EMS is responsible for distribution of physics events or event fragments sampled from defined points in the data flow chain to the software monitoring tasks, which can analyze and visualize data of the experiment. An event is transported as a sequence of bytes, so the EMS is neutral to the event format.

To transfer events of the experiment collected by the Raw Event Builder from the DAQ Transient Data storage to the Online Event Display, BM@N Event Provider producing events for monitoring and BM@N Event Consumer processing and visualizing obtained events were developed. The classes are based on the special C++ interface of the Event Monitoring Service. When the BM@N Event Consumer requests samples of events from the DAQ system, the EMS demands the BM@N Event Provider to start a sampling process via the Event Sampler interface. The BM@N Event Provider samples events and provides them to the EMS via the Event Accumulator interface. The event buffer of the Accumulator was set to 1000 raw events. The Event Consumer gets these events via the Event Iterator interface. When there are no more Event Consumers interested in event samples from a particular point, the EMS sends the message to the appropriate Event Provider via the Event Sampler interface to stop the sampling process.

Visualization of experimental hits and tracks together with the detector geometry during the experiment run is performed by the developed Online Event Display as follows. New raw events are converted on the DAQ storage to the digits by the digitizer. Then the digits are sent via the TDAQ EMS to machine with the Event Monitor for the fast clustering and tracking. The Online Event Display gets the current detector geometry from the Unified Database and continuously visualizes it with the obtained hits and tracks on the screen. The operators can interact with the Online Event Display interactively by zooming, rotating, shifting it and changing some cuts and filters.

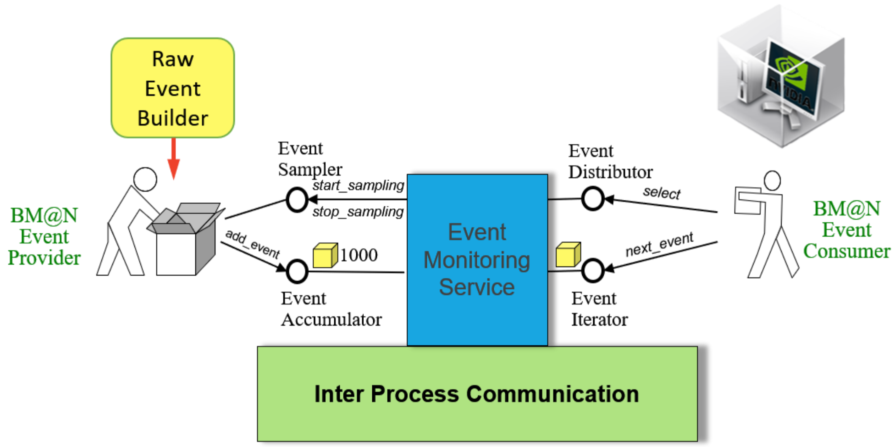

Figure 4. Remote event monitoring with the developed Online Event Display

6. Conclusion

In this work the Event Display has been developed for graphical representations of the NICA experiments in offline as well as online mode and integrated into the BmnRoot and MpdRoot software. The EVE package was chosen as a visualization software tool to show detector geometries and simulated and reconstructed event data of particle collisions: hits, clusters, points, particle tracks, active calorimeter towers. The ATLAS TDAQ components are used to transfer raw event data outside the DAQ system to visualize the NICA experiments on another machine with graphics card. It can also be used for online histogramming and Web monitoring. The Online Event Display was tested with the raw data files of the DAQ storage system. It is planned to use it for visual presentation of selective BM@N events during the future experiment runs.

References

[1] BM@N Collaboration. BM@N Project. Studies of Baryonic Matter at the Nuclotron. 2016. http://bmnshift.jinr.ru/wiki/lib/exe/fetch.php?media=bmnproject_2016.pdf.

[2] MPD Collaboration. The MultiPurpose Detector – MPD. Conceptual Design Report. JINR, Dubna, 2012. 259 p.

[3] Bauerdick L. et al. Event Display for the Visualization of CMS Events // Journal of Physics: Conference Series, 2011, Vol. 331, 072039.

[4] Tadel M. Raw-data display and visual reconstruction validation in ALICE // Journal of Physics: Conference Series, 2008, Vol.119, 032036.

[5] Bianchi R. et al. Event visualization in ATLAS // Journal of Physics: Conference Series. 2017, Vol. 898, 072014.

[6] Gertsenberger K. V. The unified database for the fixed target experiment BM@N // Physics of Particles and Nuclei Letters, 2016, Vol. 13, No. 5. pp. 634–639.

[7] ATLAS Collaboration. ATLAS High-Level Triggers, DAQ and DCS: Technical Proposal. CERN-LHCC-2000-017.

[8] Alexandrov I., Lúcio L. et al. Online Monitoring software framework in the ATLAS experiment // Proceedings of Computing in High-Energy Physics, 2003, Science Press New York Ltd.