A Comparative Study on the Detector Control Systems of ALICE at CERN and the BM@N Experiment at JINR

A B S T R A C T: This study presents a comparative analysis of Detector Control Systems (DCS) in two nuclear physics experiments: ALICE at CERN and BM@N Experiment at JINR. DCS is crucial in monitoring and controlling detectors and subsystems in particle physics. The analysis explores DCS creation, considering efficiency, quality, resource utilization, management, and risks for both experiments. It assesses design solutions for hardware, software, l ogic ware, and infoware, evaluating functionality and goal achievement indicators. Challenges in DCS design and implementation are discussed, with a focus on scalability, reliability, maintainability, and adaptability. A comparison of design documentation at different stages is conducted. The study investigates ISO and ISA standards adhered to in ALICE and the BM@N experiment for streamlined processes, compatibility, and best practices. The research assesses automation and functionality, presenting indicators of automation goal achievement.

This comprehensive analysis highlights similarities and differences between ALICE and BM@N DCS, offering insights for future nuclear physics experiments' detector control systems with ISO and ISA enhancements.

Index Terms: Detector Control System, —> *to be added as the paper progresses*

1. Introduction

ALICE, situated at the renowned European Organization for Nuclear Research (CERN), is a large-scale experiment designed to investigate the properties of matter under extreme conditions. It involves colliding heavy ions to study the characteristics of quark-gluon plasma and the formation of high-energy-density states. On the other hand, the BM@N Experiment at JINR's Veksler and Baldin Laboratory focuses on short-range correlations, aiming to explore the properties of baryonic matter through proton and heavy-ion collisions. Both experiments play vital roles in advancing our understanding of fundamental particles and the properties of matter.

In the field of nuclear physics, experiments rely on robust and efficient Detector Control Systems (DCS) to supervise and control detectors and their associated subsystems. The primary purpose of the DCS is to guarantee the proper operability of equipment within the specified technological modes. It enables researchers to maintain optimal conditions for data collection by actively monitoring the health, performance, and environmental conditions of the detectors. A well-designed efficient control system will reduce the downtime of the experiment and therefore contribute to a high running efficiency.

The Detector Control Systems analyzed in this study encompass a wide array of critical functions. It involves monitoring and primary processing of input/output signals from engineering subsystems, providing a comprehensive overview of technical processes in a single time scale. The DCS takes charge of controlling front level electronics, adjusting equipment settings, and establishing crucial technological signaling which are required to achieve the set parameters of the experiment. Moreover, it efficiently performs automatic functions and manages various technological aspects. It also plays a crucial role in configuring and setting specific parameters for different elements within the system. It is responsible for defining the operational modes of various technological units and subsystems, ensuring their efficient and coordinated functioning in alignment with the experiment's objectives. It performs essential tasks, such as executing step programs (SP) and functional-group control (FGC), which involve coordinating and managing various functions within the system. These tasks may include complex and intricate calculations that require a high level of precision and accuracy. Overall, these functions underscore the paramount importance of the DCS in ensuring smooth and effective operations of the experimental setup.

The control system is an integral part of the operational environment, which comprises four crucial components: the DCS (Detector Control System), DSS (Detector Safety System), DAQ (Data Acquisition System), and ECS (Experimental Control System). Their seamless integration forms a robust operational environment, vital for the success of the experiments.

The DCS is an interconnected system with hardware components like sensors and communication interfaces that facilitate data collection and communication between subsystems. Software encompasses programs and interfaces for detector interaction, parameter setting, and data acquisition. The DCS's logic ware employs algorithms for data processing, error handling, and control strategies, ensuring proper functioning. Infoware manages data storage, retrieval, and visualization for efficient analysis. Organization structure involves personnel, instruction sets, and user manuals, managing DCS operations. These components work together to form a comprehensive system overseeing detectors in nuclear physics experiments.

Studying and comparing the DCS of ALICE and BM@N Experiment is important. By conducting a comparative analysis, we can identify commonalities and dissimilarities in their DCS life cycles, design solutions, functionality, and associated challenges. The main question of this study is to

The research objectives of this study are threefold:

(1) To identify best practices through a comparison of key features and design approaches in ALICE and BM@N, aiming for optimal system performance and flexibility.

(2) To evaluate the operational efficiency. The volume of operational activities of operators (shifters) will be analyzed to assess system performance and efficiency during different operations. We will determine the effectiveness and reliability of automation, recommend best practices, and suggest improvements to enhance research efficiency and quality.

(3) To explore adherence to ISO and ISA standards in ALICE and BM@N, assessing the level of compatibility in their DCS.

By adhering to these objectives, this study aims to provide a comprehensive understanding of the DCS in ALICE and the BM@N Experiment, offering insights and recommendations for enhancing future detector control systems in nuclear physics experiments.

2. ALICE Detector Control System

A Large Ion Collider Experiment (ALICE), a general-purpose heavy-ion detector at CERN's LHC, is dedicated to exploring the strong-interaction sector of the Standard Model known as Quantum Chromodynamics (QCD). It delves into the physics of strongly interacting matter and quark-gluon plasma through high-energy nucleus-nucleus collisions. The collaborative effort to construct the detector involved over 1000 physicists and engineers from 105 Institutes across 30 countries. ALICE stands as a testament to international cooperation and dedication to understanding fundamental aspects of matter under extreme conditions.

The ALICE DCS has provided detector control, safe operation, and uninterrupted services to the experiment since its inception. The controls infrastructure at the experimental site became operational in early 2007, covering backend infrastructure and common services. In 2008, the complete ALICE DCS was integrated and commissioned alongside the detectors through approximately 100 individual and common integration sessions. These sessions focused on verifying system functionality, ensuring compliance with ALICE conventions, and emphasizing detector safety with interlocks and alerts. Common sessions demonstrated the DCS's ability to be controlled from a single post in the control room, while studying backend infrastructure performance. Controlled perturbations were introduced to identify irregularities, leading to system improvements. The successful development, integration, and testing allowed the ALICE DCS to be fully operational before the LHC startup and effectively supported ALICE operations with first beams.

The detector control system (DCS) for ALICE is designed with specific goals and requirements in mind. It aims to be coherent and homogeneous, ensuring easy integration of independently developed components. The DCS is designed to be flexible and scalable, accommodating changes in hardware or operational procedures throughout the experiment's lifetime. It supports various operational modes and concurrent operation, allowing different parts of the experiment to operate independently without interfering with others. The DCS prioritizes user-friendliness, intuitive operation, and automation to enhance efficiency and avoid operator mistakes. Safety and reliability are paramount, with mechanisms in place to handle hazardous situations. The system allows remote access and caters to different user types with varying requirements. It coordinates with other online systems and archives all relevant data for efficient configuration and analysis.

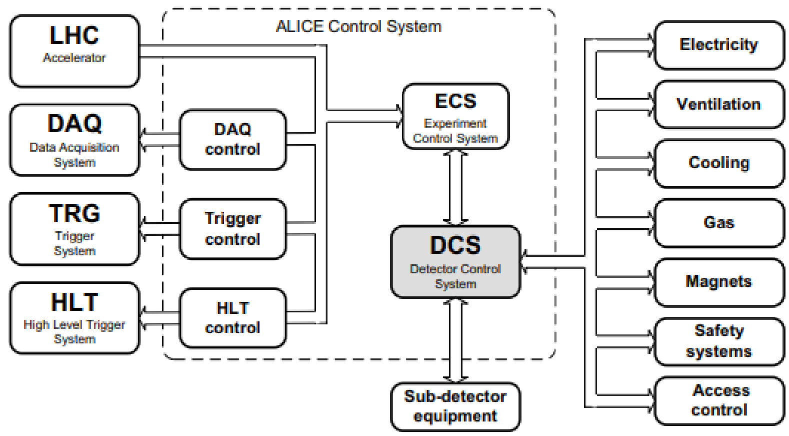

Fig.1. Contextualizing the ALICE Control System

In the CERN Style decomposition of the ALICE Control system as shown in Fig.1, the DCS is an integral part of the ECS, while maintaining its own autonomy…..add more lines to it

2.1 Quantifying the ALICE DCS

This section provides an overview of the hardware components utilized within the ALICE DCS, as well as the number of each component involved. The hardware list encompasses various types of equipment, including control computers, embedded computers, network devices, and more.

Number of Detectors Involved in ALICE	19
Number of Crates	270
Number of Control Computers	170

Number of Embedded Computers	700
Number of Network Devices	1200
number of WINCC OA systems	100
fronted services	100
supervised parameters	1000,000
OPC items	200,000

Table 1

Additionally, the DCS extends its functionality beyond the experiment's internal components. It plays a central role in monitoring and maintaining the operational integrity of several external services vital for the experiment's success. These services span a wide range of critical aspects, i ncluding electricity supply, ventilation, cooling systems, magnets, gas supply, access control, safety protocols, environmental conditions, and radiation levels. The DCS ensures the continuous oversight of these parameters, contributing significantly to the overall safety and stability of the ALICE experiment. This hardware list and monitoring of external services underscore the meticulous planning and execution required to operate a complex experiment like ALICE successfully.

2.2 DCS Architecture

Software

In the pursuit of streamlined design, standardized communication, and the augmentation of control capabilities, a dedicated software framework has been meticulously cultivated around WinCC. This framework stands as a testament to collaborative innovation, shaped by LHC experiments and CERN EN/ICE-SCD within the ambit of the Joint COntrols Project (JCOP).

Central to the framework's utility are its pivotal tools, encompassing a Finite State Machine (FSM), alarm handling mechanisms, configuration management, archiving solutions, access control protocols, user interfaces, data exchange modalities, and robust communication capabilities. These resources empower developers in the proficient creation of control applications. For applications tailored to ALICE's unique requirements, the JCOP framework is further enriched with ALICE-specific components. These components enable sub-detector experts to craft their control applications, spanning high voltage control, front-end electronics control, and more.

In a harmonious culmination, approximately 140 such applications meld into a comprehensive ALICE control system, finely tuned to orchestrate the experiment's intricate operational landscape.

The scale of data managed by the ALICE DCS signifies a paradigm shift, transcending the scope observed in prior generations of control systems. The field layer infrastructure encompasses around 1200 network-attached devices and 270 VME and power supply crates. As each physics run commences, up to 6GB of data traverse from the DCS database to the detector devices. This encompassing load incorporates WinCC recipes, encapsulating nominal device parameter values, alert thresholds, and FEE settings. Remarkably, the orchestration of ALICE for a physics run entails configuring a staggering one million parameters. This multifaceted endeavor underscores the intricate dance of technology, precision, and scale characterizing the ALICE experiment's data handling and control prowess.

Hardware System Layout

In the CERN-style model, the Experiment Control System (ECS) acts as an integral part of the ALICE control framework, overseeing and coordinating the ALICE online systems, including DCS, DAQ, TRG, and HLT. During regular operations, shift crews utilize the ECS to operate ALICE, automating routine tasks and sequences for enhanced efficiency and seamless experimentation within the broader LHC facility.

Fig.2. Hardware System Layout → to be added

In the field layer, ALICE comprises around 1200 network-attached devices and 270 VME and power supply crates, divided into approximately 150 sub-systems. These devices gather data and use the OPC protocol for communication. The FEE sub-system, specific to detectors, employs the Front End Device (FED) for standardized access, connecting FEE hardware with WINCC OA through the DIM protocol.

The controls layer employs computers and Programmable Logic Controllers (PLCs) that collect field layer data and issue control commands. WINCC OA, a core component, is used with OPC or FED servers. Over 100 WINCC systems, with 1000+ managers, are deployed for ALICE, featuring a decentralized architecture for load balancing and distributed system building.

The supervisory layer includes Worker Nodes (WN) for executing DCS tasks and Operator Nodes (ON) serving as dedicated servers for interactive interfaces. ONs prevent system overload by separating interactive tasks from control functions, ensuring smooth operation.

User Interface

In the ALICE Detector Control System (DCS), a standardized Graphics User Interface (GUI) is a central control hub that maintains a consistent look and functionality across all DCS components. It offers features like hierarchy browsing, alert monitoring, and access to the Finite State Machine (FSM) and status monitoring. The GUI ensures role-based access control for added reliability and safety, organizing controls for intuitive operation and efficient monitoring of the ALICE experiment.

2.3 DCS Dataflow

The volume of data managed by the ALICE DCS significantly surpasses the capacity of previous-generation control systems. To support the field layer infrastructure, approximately 1200 network-attached devices and 270 VME and power supply crates are required. At the commencement of a physics run, a substantial load of data, up to 6GB, is transmitted from the DCS database to the detector devices. This data encompasses WINCC OA recipes, encompassing nominal device parameter values, alert thresholds, and FEE settings, totaling around one million parameters to be configured to prepare ALICE for experimentation.

WINCC OA continuously monitors these parameters, reading approximately 300,000 values per second through OPC and FED servers. To optimize data traffic, initial filtering is applied at the first level stage, allowing only values exceeding predefined thresholds to be injected into the WINCC OA systems. This filtering mechanism achieves a ten-fold reduction in data volume. Each processed value is first compared to the nominal one, generating an alert on operator screens if the difference exceeds the limit, with automatic actions based on severity.

Values marked for archiving by system experts are transferred to the DCS archival database. To reduce storage requirements, an additional level of filtering is implemented, recording only values falling outside a predefined band around previously archived values. This smoothing process significantly reduces the data written by ALICE DCS to the database to approximately 1,000 inserts per second.

Six main database servers, equipped with a redundant storage capacity of 20TB, are configured to handle a peak insertion rate of 150,000 SQL inserts per second. This accommodates the steady ALICE insertion rate as well as peak loads during detector configuration and voltage ramping. The entire data flow within ALICE DCS is summarized in Figure 3 below

Fig.3. DCS Dataflow → to be added

2.4 Organization Structure and Standardization

(TO BE ADDED TAKING CONTENT FROM MUHAMMEDS PAPER ON THE ORGANIZATION STRUCTURE OF THE CCC)

3. BM@N Slow Control System

The BM@N Experiment, situated within the NICA complex of the Veksler and Baldin Laboratory of High Energy Physics at JINR, is a focused endeavor dedicated to understanding the properties of baryonic matter through proton and heavy-ion collisions. This research effort delves into the intricate realm of short-range correlations, aiming to shed light on fundamental aspects of matter. Much like ALICE, the BM@N Experiment represents an international collaboration, bringing together scientists and engineers from various institutes and countries to advance our understanding of the fundamental particles and matter's properties under specific conditions.

The BM@N Experiment's Detector Control System (DCS) plays a pivotal role in overseeing and managing the detectors and their subsystems. This control system is designed to ensure the proper operation of equipment in alignment with the experiment's technological requirements. It actively monitors the detectors' health, performance, and environmental conditions to maintain optimal data collection conditions. The DCS for the BM@N Experiment, similar to that of ALICE, encompasses a wide array of functions, including monitoring and primary signal processing, control of front-level electronics, and the establishment of critical technological signaling to achieve experiment parameters.

In addition, the BM@N Experiment's DCS efficiently performs automated functions and manages various technical aspects to ensure smooth and coordinated operations of subsystems. It is responsible for configuring and setting specific parameters for different elements within the system. The DCS defines operational modes for various technological units and subsystems to align with the experiment's objectives. It performs essential tasks, including the execution of step programs and functional-group control, which involve coordination and management of various functions. Furthermore, it efficiently handles logging, electronic logging, and reporting processes, critical for recording and documenting system activities and events. Overall, the DCS in the BM@N Experiment is integral to ensuring the reliability of data, improving experimental efficiency, and enhancing the quality of scientific investigations.

Just like ALICE, the BM@N Experiment integrates the DCS within its Experimental Control System (ECS). It is an essential component of the BM@N operational environment, working seamlessly alongside the Detector Safety System (DSS), Data Acquisition System (DAQ), and Experimental Control System (ECS). This harmonious integration ensures the successful execution of experiments at the BM@N facility and plays a crucial role in advancing our understanding of fundamental particles and the properties of matter in the field of nuclear physics.

Overall, the BM@N Experiment, guided by its Detector Control System and within the framework of the ECS, is dedicated to achieving significant scientific discoveries in the realm of high-energy physics, much like its counterpart, ALICE at CERN.

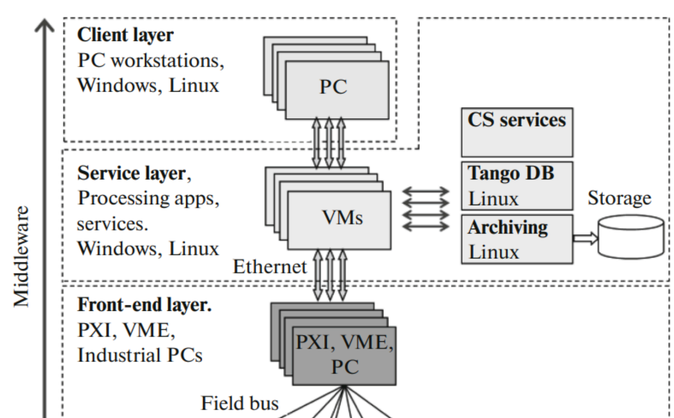

Fig.4. Contextualizing the BM@N Control System

3.1 Quantifying the BM@N DCS

This section provides an overview of the hardware components utilized within the BM@N DCS, as well as the number of each component involved. The hardware list encompasses various types of equipment, including control computers, embedded computers, network devices, and more.

Number of Detectors Involved in the BM@N Experiment	10 (ALL the detectors have their own localized control systems and operate independently with minor feedback from the DCS.)
Number of Crates	8
Number of Embedded Computers or Network Devices	54
Number of Control Computers or Servers	2 (1 main server and 1 reserve server)
Number of SCADA Systems	TangoControl (sole SCADA system employed)

Table 2

It oversees critical factors such as electricity supply, backup power systems, temperature levels, humidity levels, and radiation levels. The DCS ensures the continuous monitoring of these vital parameters, actively contributing to the overall safety and stability of the experimental facility.

3.2 DCS Architecture

Software

(DCS) in this setup employs the Tango SCADA system for its comprehensive monitoring and control capabilities. To facilitate its implementation, specific frameworks have been utilized. The PyTango framework, designed for Python, plays a pivotal role in the development process. Additionally, PySide is harnessed to construct the graphical user interface (GUI) for the DCS, enhancing user interaction and visualization. Complementing these frameworks, the DCS integrates CAEN Crate control through gecko and custom in-house applications, adding a layer of versatility to its functionality.

The integration of the SCADA system with hardware is a meticulous process that involves connection protocols to ensure effective communication. The DCS leverages a range of protocols, including MODBUS TCP, SNMP, socket interfaces, and OPC UA, enabling seamless interactions with diverse hardware components and sub-systems. Notably, the development of Programmable Logic Controllers (PLCs) was not pursued, as the digital detector signals are directly managed by field-level electronics and subsystems, eliminating the need for intermediary PLCs.

Understanding the software structure of the DCS can be aided by referring to available documents. However, specific documents detailing this aspect were not specified. The system testing and commissioning phase is a crucial step in ensuring operational readiness. For this particular setup, rigorous system testing is performed in designated test tents, involving all detector groups, approximately 2-3 months before the initial run. Subsequent to the first run, changes were made to enhance the DCS's performance. Notably, the transition from a desktop application to a web application for monitoring and control was implemented, offering increased accessibility and flexibility. Furthermore, multiple new applications were introduced, enabling the controlled management of individual subsystems, a departure from the initial single-application approach.

Hardware System Layout

The Detector Control System (DCS) of the BM@N experiment operates as an autonomous entity within the experimental setup, overseeing its specific functions without direct hierarchical oversight. Similarly, the Data Acquisition (DAQ) system and the Trigger System function as distinct and independent bodies, each managing its designated responsibilities. This decomposition style ensures that the DCS, DAQ system, and Trigger System operate cohesively while maintaining separate management structures.

As described in figure 4 above, it is clear that the main hardware system layout of the BM@N DCS is further divided into 3 main layers.

Three layers of the BM@N control system components can be distinguished and described as :

(1) The front-end layer consists of industrial computers, intellectual controllers, and crates that directly manage equipment and gather data from sensors. The front-end computers execute low-level TANGO programs responsible for data acquisition, equipment manipulation, and the abstraction of protocol and connection intricacies from higher-layer components.

(2) The service layer comprises high-level TANGO devices that represent complete subsystems. These devices gather data from front-end TANGO devices, process it, and implement algorithms to regulate larger subsystems. These high-level programs offer a standardized TANGO interface for whole subsystems, enabling client software to execute commands, access attributes, and perform read and write operations without necessitating knowledge of the underlying subsystem structure. Additionally, the service layer supplies a suite of services crucial for the efficient operation of the control system, encompassing administration, management of control system hardware and software, monitoring, data archiving, and development services.

(3) The client layer presents the accelerator complex state to the operator, visualizes acquired data, and empowers the operator to execute control actions. The aim is to offer a comprehensive interface enabling the operator to access the entire accelerator complex control, with the added capability to navigate to its individual components.

User Interface

The BM@N DCS User Interface (UI) offers an organized hierarchy for quick access to sub-detector systems, promoting efficient user interaction. It employs color coding for error recognition, transitioning from green to red. The main screen provides comprehensive information on system parameters and real-time updates. The UI accommodates different user roles, employing Linux Debian-based software compatible with the Tango control system. This design facilitates navigation, quick decision-making, and accessibility. The Slow Control system has performed well in previous runs, and expansion plans involve more connected devices and improved notification systems for the future.

3.3 DCS Dataflow

The data flow architecture of the DCS, encompassing data sources and pathways, was not elaborated upon. In terms of data management, the DCS handles a substantial amount of information during each run. An estimated average of 5 million events are managed in total for the experiment, with the DAQ servers responsible for processing the experimental data portion. This comprises around 50 GB of slow control data. To accommodate this influx of data, the DCS relies on various databases. Three database servers are employed, including one dedicated to archive data and two others for reading data, such as utilizing Graphene. These servers serve not only as data repositories but also act as backups for other servers, contributing to data redundancy and system reliability.

Fig.5. DCS Dataflow → to be added

3.4 Organization Structure and Standardization

(TO BE ADDED taking reference from the same section of the ALICE DCS)

4. Comparative Analysis

5. CONCLUSION —> conclusion idea

DCS has to cover the lifetime of the experiment

Due to the planned upgrades of

sub-detectors, the control system

should be flexible enough to

accommodate the integration of new

components and adapt to changes in

hardware and operational procedures.

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