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VEKSLER AND BALDIN LABORATORY OF HIGH ENERGY PHYSICS

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Control Systems at the NICA Accelerator Complex

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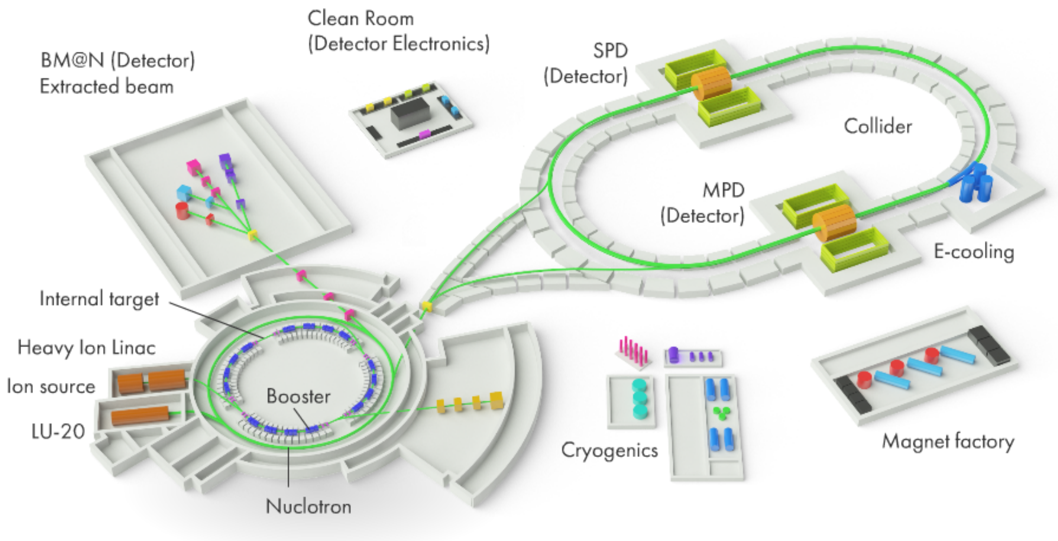
Abstract

The project deals with the comparison of the two major experiments set up at Joint institute of Nuclear Research, JINR and at the European Organization for Nuclear Research, CERN. The major aspect of the project was to identify different parameters suitable for comparing the two experiments set up which were Baryonic Matter at Nuclotron - BM@N and A Large Ion Collider Experiment - ALICE. The experiments were studied although with limited and restricted data to find suitable parameters that could be defined for comparison. The project discussed here deals with some initial study of BM@N and ALICE. The further work progress focused mainly on BM@N experiment and its various parameters.

1. Introduction

- **Nuclotron-based Ion Collider fAcility – NICA**

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex designed at the Joint Institute for Nuclear Research (Dubna, Russia) to study properties of dense baryonic matter. After puting the NICA collider into operation JINR scientists will be able to create in the Laboratory a special state of matter in which our Universe stayed shortly after the Big Bang – the Quark-Gluon Plasma (QGP). It is perform experiments such as Nuclotron ion beams extracted to a fixed target and colliding beams of ions, ions-protons, polarized protons and deuterons. The projected maximum kinetic energy of the accelerated ions is 4.5 GeV per nucleon, and 12.6 GeV for protons.



Main elements of the NICA complex are:

- Two-tier injection complex
- Booster
- Superconducting synchrotron Nuclotron
- Collider facility
- Multi-Purpose Detector (MPD)
- Spin Physics Detector (SPD)
- Beam transport channels.

LU-20 injection device produces ions of 5 MeV/n energy. It is succeeded by three-staged Light Ion Linac (LILAc) that is capable of light particles acceleration up 7 MeV/n energy, 13 MeV proton acceleration section and a 20 MeV superconducting HWR proton accelerating section. Heavy-Ion Linac (HILAc), conceived in 2016 by the JINR-Bevatech collaboration, accelerates heavy gold ions up to the energy of 3.2 MeV/n with beam intensity of 2×109 particles per pulse, and a repetition rate of 10 Hz. The gold ions are injected from a JNIR-made KRION superconducting electron-string heavy ion source.

The Booster, a superconducting synchrotron, accumulates, cools and further accelerates heavy ions to 600 MeV/n energy. The booster's circumference is 211 meters, its magnetic structure is mounted inside the yoke of the Nuclotron. The Booster is supposed to ensure ultrahigh vacuum of 10−11 Torr. The Nuclotron to be used in NICA was constructed in 1987–1992. It is the world's first synchrotron based on fast cycling electromagnets of the 'window frame' type with superconducting coil.

The collider is made of two identical 503-meter long storage rings with MPD and SPD placed in the middle of the opposite straight sections. Magnetic rigidity is up to 45 Tm, residual gas pressure in the beam chamber is below 10−10 Torr, maximum field in the dipole magnets – 1.8 T, kinetic energy of gold nuclei – 1.0 to 4.5 GeV/n. The beams are combined and separated in the vertical plane. Upon passing the section bringing them together, the particle bunches in the upper and lower rings travel along a common straight trajectory toward each other to collide at MPD and SPD. Single-aperture lenses are installed along the final focus sections to provide that both beams are focused at SPD and MPD.

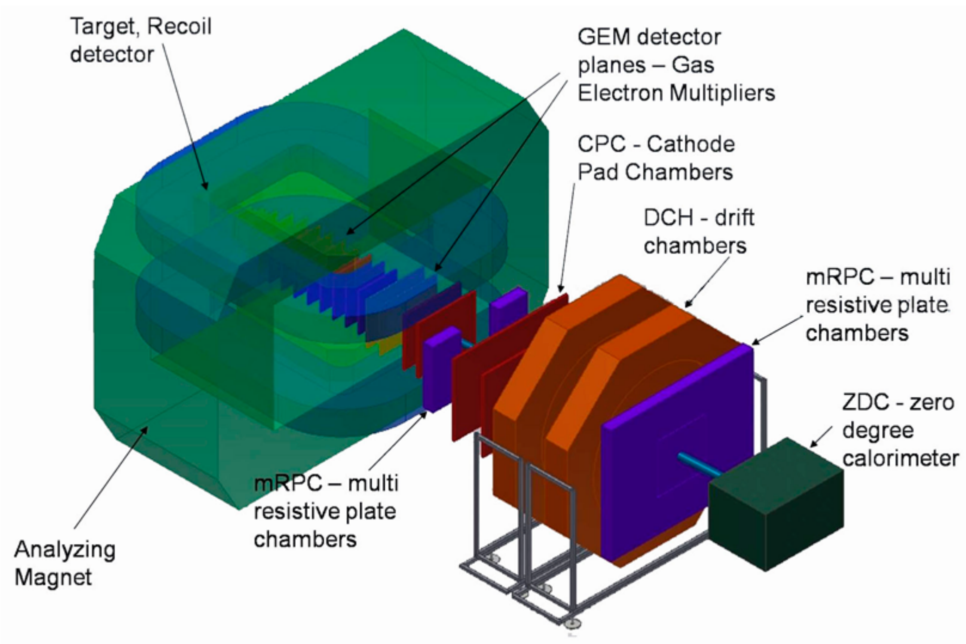
MPD facility is designed to study hadron matter at high temperatures and densities, where nucleons "melt" releasing their constituent quarks and gluons and forming a new state, the quark-gluon plasma. SPD facility allows to collide the polarized beams of protons and deuterons to study the particle spin physics.

- **Veksler and Baldin Laboratory of High Energy Physics**

The Veksler and Baldin Laboratory of High Energy Physics – JINR VBLHEP – was established in Dubna in 1956 based on the Electrophysical Laboratory of the USSR Academy of Sciences. It was originally known as the Laboratory of High Energies (LHE). The founder of LHE and its first Director (1956-1966) was Vladimir Veksler, a talented scientist and organizer. He discovered the principle of autophasing, which underlies the operation of all modern high-energy cyclic accelerators. He led an ambitious project to construct the largest accelerator in the world at that time, the Synchrophasotron. In April 1957, the Synchrophasotron reached a record proton beam energy of 10 GeV. A decisive contribution to the construction of the accelerator was made by Leonid Zinoviev. He was in charge of the development of its model at the Lebedev Physics Institute in Moscow, and then, as head of the department, he supervised the construction and launch of the Synchrophasotron at JINR LHE. The launch of the Synchrophasotron caused a wide resonance in the world and was recognized as an outstanding achievement of science. The research programme at the Synchrophasotron was developed and performed under the leadership of V. Veksler, M. Markov and I. Chuvilo, who later became the second Director of LHE (1966-1968).

- **Baryonic Matter at Nuclotron (BM@N)**

The Nuclotron at JINR will provide beams of heavy ions with energies up to 6A GeV for isospin symmetric nuclei, and 4.65A GeV for Au nuclei. In central heavy-ion collisions at these energies, nuclear densities of about 4 times nuclear matter density can be reached. These conditions are well suited to investigate the equation-of-state (EOS) of dense nuclear matter which plays a central role for the dynamics of core collapse supernovae and for the stability of neutron stars. At the same time, heavy-ion collisions are a rich source of strangeness, and the coalescence of kaons with lambdas or of lambdas with nucleons will produce a vast variety of multi-strange hyperons or of light hypernuclei, respectively. Even the production of light double-hypernuclei or of double-strange dibaryons is expected to be measurable in heavy-ion collisions at Nuclotron energies. The observation of those objects would represent a breakthrough in our understanding of strange matter, and would pave the road for the experimental exploration of the third (strangeness) dimension of the nuclear chart. The extension of the experimental program is related with the study of in-medium effects for vector mesons and strangeness decaying in hadronic modes. The studies of the p+p and p+A reactions for the reference is assumed. Possible measurements of the electromagnetic probes is under discussion.



For these purposes, it is proposed to install an experimental setup in the fixed-target hall of the Nuclotron with the final goal to perform a research program focused on the production of strange matter in heavy-ion collisions at beam energies between 2 and 6A GeV. The basic setup will comprise a large-acceptance dipole magnet with inner tracking detector modules based on double-sided Silicon micro-strip sensors and gaseous detectors. The outer tracking will be based on the drift chambers and straw tube detector. Particle identification will be based on the time-of-flight measurements. The first commissioning run is scheduled for 2015.

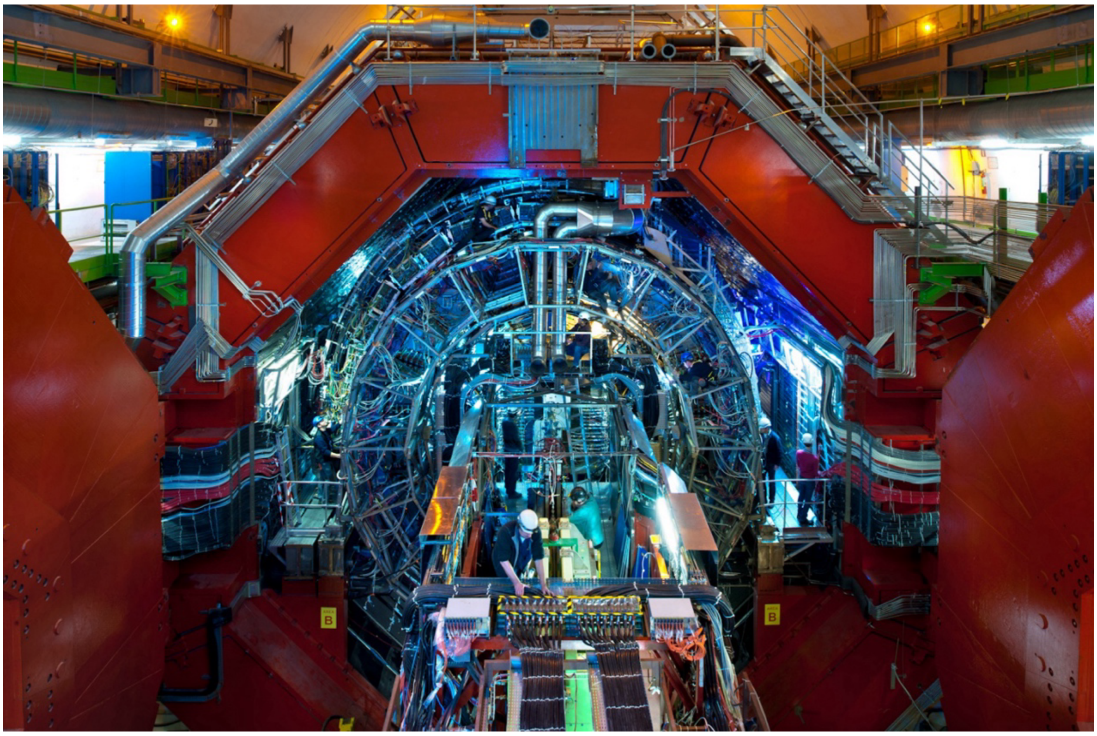
Physics for the first stage of the BM@N spectrometer (start in 2015):

In-medium effects for strangeness and vector mesons decaying in hadron modes;
Flows, polarizations, azimuthal correlations of hadrons, vorticity;
Femtoscopy for different hadrons; pp and pA interactions as the reference for AA collisions.
Physics for the BM@N spectrometer with silicon inner tracker (start in 2017): The measurements of the (sub)threshold cascade-hyperons production in order to obtain the information on the nuclear matter EOS.

- **A Large Ion Collider Experiment - ALICE CERN**

ALICE (A Large Ion Collider Experiment) is a detector dedicated to heavy-ion physics at the Large Hadron Collider (LHC). It is designed to study the physics of strongly interacting matter at extreme energy densities, where a phase of matter called quark-gluon plasma forms.

All ordinary matter in today's universe is made up of atoms. Each atom contains a nucleus composed of protons and neutrons (except hydrogen, which has no neutrons), surrounded by a cloud of electrons. Protons and neutrons are in turn made of quarks bound together by other particles called gluons. No quark has ever been observed in isolation: the quarks, as well as the gluons, seem to be bound permanently together and confined inside composite particles, such as protons and neutrons. This is known as confinement.



Collisions in the LHC generate temperatures more than 100 000 times hotter than the centre of the Sun. For part of each year the LHC provides collisions between lead ions, recreating in the laboratory conditions similar to those just after the Big Bang. Under these extreme conditions, protons and neutrons "melt", freeing the quarks from their bonds with the gluons. This is quark-gluon plasma. The existence of such a phase and its properties are key issues in the theory of quantum chromodynamics (QCD), for understanding the phenomenon of confinement, and for a physics problem called chiral-symmetry restoration. The ALICE collaboration studies the quark-gluon plasma as it expands and cools, observing how it progressively gives rise to the particles that constitute the matter of our universe today. The ALICE collaboration uses the 10 000-tonne ALICE detector – 26 m long, 16 m high, and 16 m wide – to study quark-gluon plasma. The detector sits in a vast cavern 56 m below ground close to the village of St Genis-Pouilly in France, receiving beams from the LHC. The collaboration includes almost 2000 scientists from 174 physics institutes in 40 countries (April 2022).

2. Project Outline

The project aims to develop a comparative study on the two major experiments conducted – BM@N at JINR and ALICE at CERN. The major task would be to find different comparable parameters found between the two and develop a comparison table for both of them to be used towards a manuscript. The part of the project that I deal with includes the BM@N at JINR and its associated comparable parameters.

3. General comparison between BM@N and ALICE

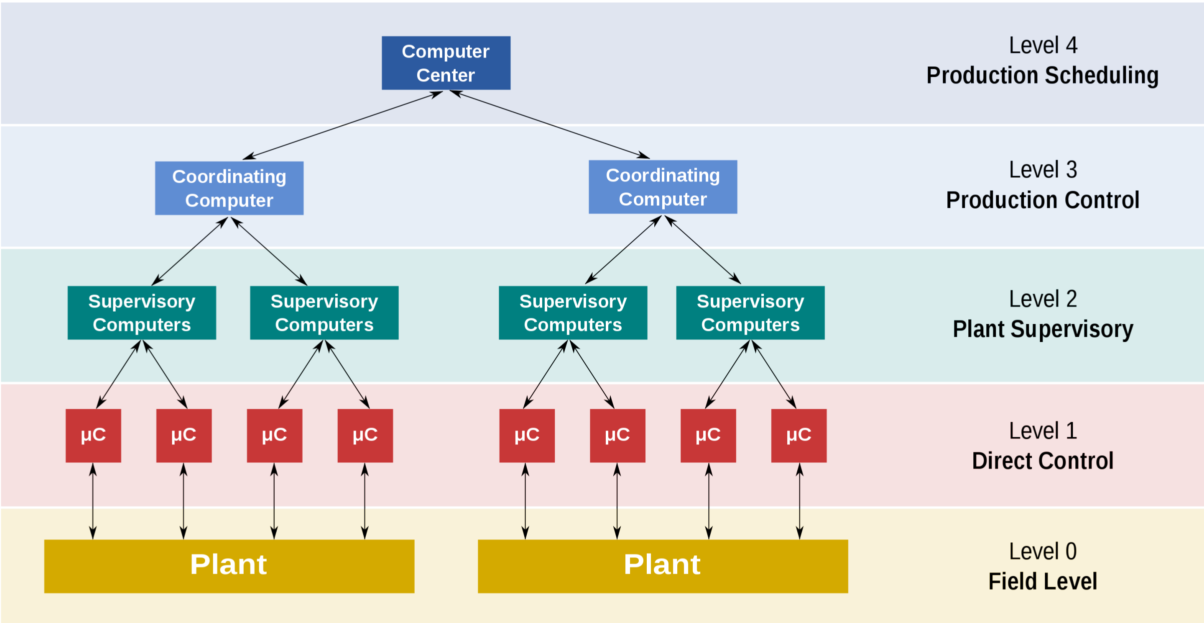
The BM@N experiment at JINR and the ALICE experiment at CERN both have their own similarities and differences. The BM@N project aims to study the properties and behaviour of baryons, composite particles composed of three quarks (e.g., protons and neutrons) while the ALICE is dedicated to study heavy-ion collisions at the Large Hadron Collider (LHC) with a primary goal of investigating the properties of quark-gluon plasma. BM@N focuses on the Nuclotron, being a heavy-ion accelerator, which could produce collisions of various heavy ions, potentially providing insights into the behavior of baryonic matter under extreme conditions. ALICE focuses mainly on lead-lead (Pb-Pb) collisions, exploring the transition from hadronic matter to quark-gluon plasma. Before we start off with the topic, for a better understanding, a comparison of the experiments are provided in the table given below.

BM@N	ALICE
□ First experiment at the accelerator complex of NICA Nuclotron □ Aim - To study interactions of relativistic heavy ion beams with fixed targets □ Nuclotron kinetic energy of ions - 1 to 6 GeV per nucleon □ Maximum kinetic energy for □ ions with (Z/A) of 1/2 is 6 GeV per nucleon, □ Heavy ions with Z/A ~ 1/3 is 4.5 GeV per nucleon □ Protons is 13 GeV □ Beam line between the Nuclotron and the BM@N experiment is around 160 meter in length □ It comprises 26 elements of magnetic optics: 8 dipole magnets and 18 quadruple lenses □ The planned intensity of the gold ion beam at BM@N is few 106 ions/s. □ The acquisition rate of non-peripheral collisions is expected to range from 20 to 50 kHz	□ Detector dedicated to heavy-ion physics at the Large Hadron Collider (LHC) □ Aim - To study the physics of strongly interacting matter at extreme energy densities, where a phase of matter called quark-gluon plasma forms. □ Generate temperatures more than 100000 times hotter than the centre of the Sun. □ Protons and neutrons "melt", freeing the quarks from their bonds with the gluons. □ ALICE collaboration studies the quark-gluon plasma as it expands and cools □ The ALICE collaboration uses the 10 000-tonne ALICE detector – 26 m long, 16 m high, and 16 m wide – to study quark-gluon plasma. The detector sits in a vast cavern 56 m below ground

4. Distributed Control Systems

A distributed control system (DCS) is a platform for automated control and operation of a plant or industrial process. A DCS combines the following into a single automated system: human machine interface (HMI), logic solvers, historian, common database, alarm management, and a common engineering suite. It is a Platform for automated controls that helps with the operation of a plant or industrial process.

It combines the following into a single automated system.
- Human machine interface (HMI)
- Logic solvers
- Historian
- Common database
- Alarm management
- Common engineering suite



Why use Distributed Control Systems?

- Real-time Monitoring and Control
- Data Acquisition and Management
- Safety Measures and System Protection
- Experiment Integration
- Environmental Monitoring
- Remote Access and Control
- Adaptability and Scalability
- Data Analysis Support

5. DCS Comparison between BM@N and ALICE

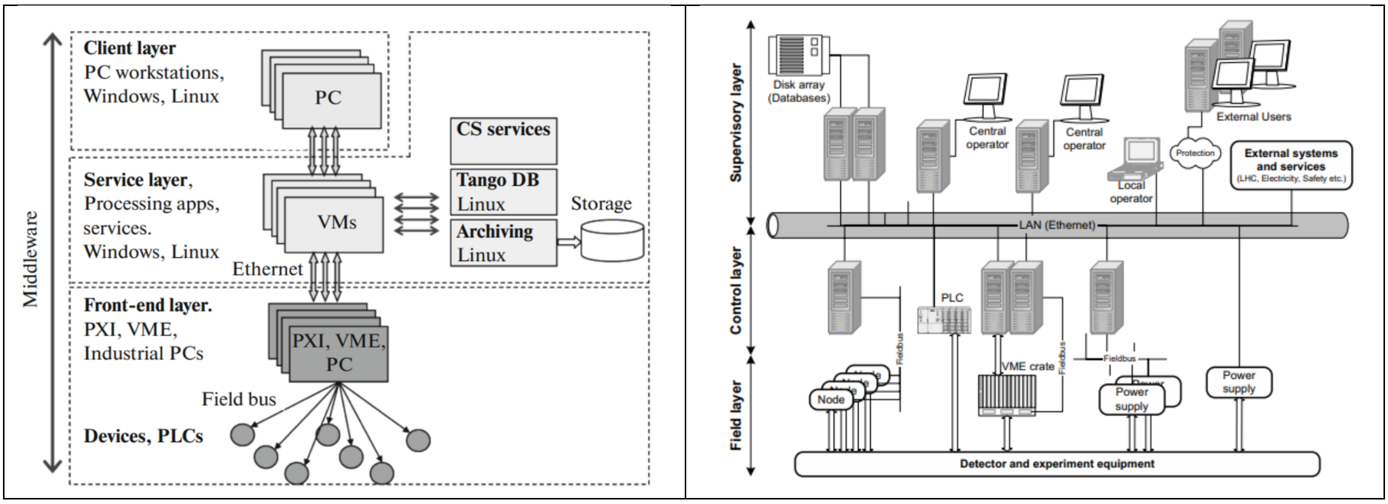
Although they are different experiments being run at two world class centres, both DCS systems would utilize advanced control technologies to ensure precision and reliability in managing experimental parameters. It also might include collaboration among scientists, engineers, and researchers in designing and implementing the DCS. Integration with other control systems and collaboration tools is crucial for efficient operation and data analysis in both experiments. The DCS for BM@N, focusing on baryonic matter studies, would be designed to control and monitor the equipment related to the generation and analysis of heavy-ion collisions. The DCS for ALICE is designed to control and monitor various components involved in heavy-ion collisions, ensuring the experiment operates according to specified parameters during lead-lead (Pb-Pb) collisions.

BM@N	ALICE
• Control mechanisms are facilitated through various graphical user applications (GUI apps), enabling shifters to efficiently manage and regulate subsystems • the DCS operates under different modes, with sub-detector states being localized for tailored status information • Specialized automation includes the implementation of a control loop to regulate the temperature of front-end chips • The DCS employs a graphical representation for alarms, with different colors denoting distinct conditions • Number of alarms lies in the hundreds, spanning scenarios from hardware disconnection to voltage operations • Shift leaders play a central role in providing guidance and directives for effective resolution	• The front-end electronics comprise 3276 front-end cards (FEC), each designed for specific tasks • Monitoring relies on a 12-bit SCA (Successive Approximation) ADC, encompassing various measurements. • Includes RTD temperature sensors, a low tolerance reference resistor for precise internal current source measurement, internal temperature sensing, shunt resistors for voltage line inputs, voltage measurements for regulators, and VTRx photocurrent measurements • SCA manages power on/off for SAMPAs (Signal APd Readout ASICs) through GPIO signals, GBTx (Gigabit Transceiver) configuration (GBTx1 post-power-up), and potentially required GBTx tuning (GBTx0) • Common Readout Unit (CRU) monitoring through aliECS includes aspects like MPO optical power, link status, temperatures, and potential voltages.

6. Architecture Comparison between BM@N and Alice

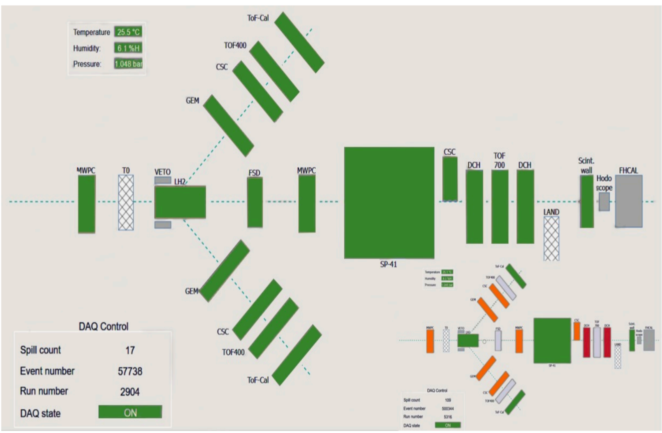
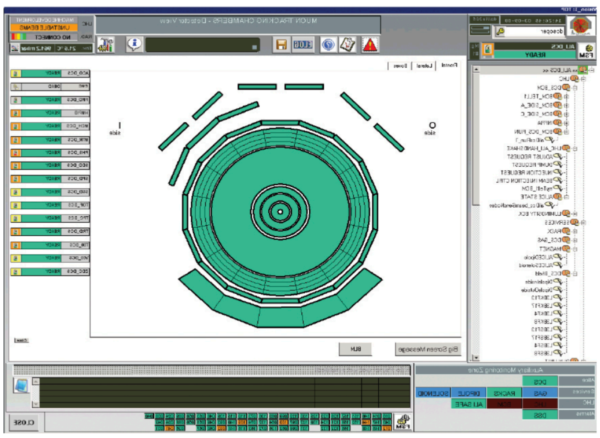
The architecture model of both the experiments can be assumed to be quite resonating. The Detector Control System (DCS) of the BM@N experiment operates as an autonomous entity within the experimental setup, overseeing its specific functions without direct hierarchical oversight. Similarly, the Data Acquisition (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. In the CERN-style model, the Experiment Control System (ECS) supervises the Detector Control System (DCS) and acts as a logical part of the ALICE control framework. The ALICE online systems, including DCS, DAQ, TRG, and HLT, are interconnected through the ECS, forming a cohesive control layer. The ECS synchronizes and coordinates these systems, along with the LHC machine, ensuring their seamless operation. During regular operations, shift crews operate ALICE through the ECS, which also automates routine tasks and predefined sequences. This setup enhances operational efficiency and minimizes manual intervention, facilitating smooth experimentation and integration with the broader LHC facility.

BM@N	ALICE
• Autonomous entity within the experimental setup • Data Acquisition (DAQ) system and the Trigger System function as distinct and independent bodies • Decomposition style ensures that the DCS, DAQ system, and Trigger System operate cohesively • Maintain separate management structures. • The front-end layer consists of industrial computers, intellectual controllers, and crates • Directly manage equipment and gather data from sensors • The service layer comprises high-level TANGO devices that represent complete subsystems • The client layer presents the accelerator complex state to the operator, visualizes acquired data, and empowers the operator to execute control actions	• The Experiment Control System (ECS) supervises the Detector Control System (DCS) • Logical part of the ALICE control framework • Includes DCS, DAQ, TRG, and HLT, are interconnected through the ECS, forming a cohesive control layer • ECS synchronizes and coordinates these systems, along with the LHC machine • Multiple subsystems, each focused on specific devices like Low Voltage (LV), High Voltage (HV), Front End and Readout Electronics (FEE), etc • 150 sub-systems, comprising around 1200 network-attached devices and 270 VME and power supply crates • FEE sub-system, distinctive and specific to detectors, employs the Front End Device (FED) as a standardized access mechanism


Middleware
Client layer
PC workstations,
Windows, Linux
PC
CS services
Service layer,
Processing apps,
services.
Windows, Linux
VMs
Tango DB
Linux
Storage
Archiving
Linux
Ethernet
Front-end layer.
PXI, VME,
Industrial PCs
PXI, VME,
PC
Field bus
Devices, PLCs
Supervisory layer
Disk array
(Databases)
Central
operator
Central
operator
External Users
Protection
External systems
and services
(LHC, Electricity, Safety etc.)
Local
operator
LAN (Ethernet)
Control layer
PLC
Fieldbus
VME crate
Fieldbus
Fieldbus
Field layer
Node
Power
supply
Power
supply
Detector and experiment equipment

7. Graphical User Interface Comparison Between BM@N and ALICE

The User Interface (UI) of the BM@N DCS offers an organized and navigable hierarchy of panels, enabling swift access to various sub-detector systems from the main panel. This intuitive navigation enhances user interaction during operation. While there's no explicit passportization of objects or labelling (faceplates), denomination of symbols employs colour coding, transitioning from green to red in case of errors, ensuring easy recognition of critical states. In the ALICE Detector Control System (DCS), a standardized Graphics User Interface (GUI) is a pivotal component employed across all detectors. Positioned as the top layer within the ALICE DCS architecture, this GUI serves as a central control hub, ensuring consistent aesthetics and functionality across all DCS components. This cohesive design is upheld through the provision of tools and guidelines, ensuring a unified "look and feel" throughout the system.

BM@N	ALICE
• Organized and navigable hierarchy of panels • Swift access to various sub-detector systems from the main panel, enhances user interaction • No labelling of objects • Denomination of symbols employs colour coding, transitioning from green to red in case of errors, ensuring easy recognition of critical states. • Including critical system parameters, real-time status updates, and visual representations of the experiment's components • Optimizing efficiency by catering to specific roles rather than individual preferences • Linux Debian-based operating system suited for TANGO Control system • Facilitate efficient navigation, provide vital information at a glance, and enable swift decision-making in the operation and management of the experiment's complex systems.	• Standardized Graphics User Interface (GUI) • Serves as a central control hub, ensuring consistent aesthetics and functionality across all DCS components • Upheld through the provision of tools and guidelines • Includes a hierarchy browser for seamless navigation, alert overview for quick identification of critical situations, and direct access to the Finite State Machine (FSM) and status monitoring • For standard actions, the FSM mechanism is employed, while for more specialized tasks, direct interactions occur through the WINCC framework. • Role-based access control mechanism(overall reliability and safety of the system)
	

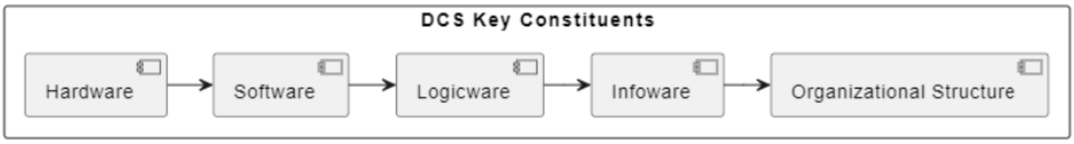
8. Detector Control Systems (DCS) for actual representation of low degree of automation at BM@N- JINR

A low degree of automation is done at the BM@N DCS because of the following reasons.

- Certain aspects of the detector control may rely on manual intervention rather than fully automated processes.
- This could involve human operators making adjustments or configurations based on experimental needs.
- The DCS components may not be highly integrated with each other or with other systems, leading to a more modular and manually coordinated approach to control.
- The user interfaces for controlling and monitoring the detectors may be more straightforward and require more direct input from operators.
- The DCS may have limited adaptive capabilities, meaning that it might not adjust configurations dynamically based on changing experimental conditions.

The DCS of BM@N primarily composes of 5 Parts

- Hardware
- Software
- Logicware
- Infoware
- Organizeware



This is majorly taken into consideration at four different levels

- Field Level
- PLC
- Server
- Suspension Level

⇒ **Hardware**

- For collection Displaying and processing of Data along with control
- Involves The Field level, PLC, Server and Supervision Level
- Comprises physical devices and instruments necessary for the operation and monitoring of detectors and experimental systems.
- This includes sensors, actuators, data acquisition systems, communication interfaces, and other devices that interact with the experiment's physical components.
- Hardware elements collect data from detectors, trigger mechanisms, and other experiment-specific instruments, transmitting this information to the software layer for processing and analysis.

⇒ **Software**

- Firmware operation system basic software protocols application software SCADA
- Involves The Field level, PLC, Server and Supervision Level
- Encompasses a range of programs, algorithms, and scripts designed to control and manage the experiment's hardware components.
- This includes control algorithms that regulate detector parameters, trigger conditions, and data acquisition processes.
- Moreover, software interfaces provide user-friendly platforms, such as Human-Machine Interfaces (HMIs), through which experiment operators and researchers interact with the DCS.
- The software layer enables real-time control, data visualization, and automated responses to various experimental conditions.

⇒ **Logicware**

- Logical Components for the automation of workflow
- Involves PLC, Server and Supervision Level
- Composes of logical rules, scripts, and decision-making processes that govern the behaviour of DCS.
- It involves defining conditions, thresholds, and actions that the system should take in response to specific events or measurements.
- Logicware ensures that the DCS reacts appropriately to anomalies, deviations, or critical events, thus maintaining the experiment's integrity and safety.
- For instance, logicware can dictate emergency shutdown procedures if certain conditions are met, preventing potential equipment damage.

⇒ **Infoware**

- Structured design, Operational configuration information in the final GUI
- Involves Server and Supervision Level
- Includes managing and processing the vast amount of data generated by detectors and experiment components.
- It includes data processing algorithms, storage solutions, and data analysis tools.
- Infoware ensures that collected data is organized, archived, and made accessible for further analysis, interpretation, and collaboration among researchers.
- Additionally, infoware may involve data visualization tools to help researchers comprehend complex datasets.

⇒ **Organiseware**

- Technological information, user’s manual, basically the operating personnel
- Involves only the supervision level of the DCS
- It establishes roles, responsibilities, and communication channels among individuals involved in operating, maintaining, and utilizing the system.
- This structure encompasses researchers, engineers, operators, and other stakeholders who collaborate to ensure the efficient operation of the DCS.
- Clear lines of communication and well-defined responsibilities are essential to effectively manage the DCS throughout the experiment's lifecycle.

- In essence, the constitution of the DCS in high-energy physics experiments is a holistic framework that synergistically combines hardware, software, logicware, infoware, and a well-structured organization.
- This comprehensive approach ensures that experiments are conducted with precision, reliability, and safety, allowing researchers to extract valuable insights from the intricate world of particle interactions.

9. Hardware Components of the DCS system of BM@N

- DCS DAQ and Trigger system
- The DCS of the BM@N setup operates independently without any direct involvement in the other steps of the process.
- The DAQ and trigger system are present as distinct and independent bodies managing their own designated responsibilities.
- Even though they operate independently from each other, their combined action is what leads to the cohesive operation of the BM@N experiment

10. Hardware Components Quantitative List

Number of Detectors Involved in the BM@N Experiment	10 (Some 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)

11. Number of External Services Monitored by the DCS

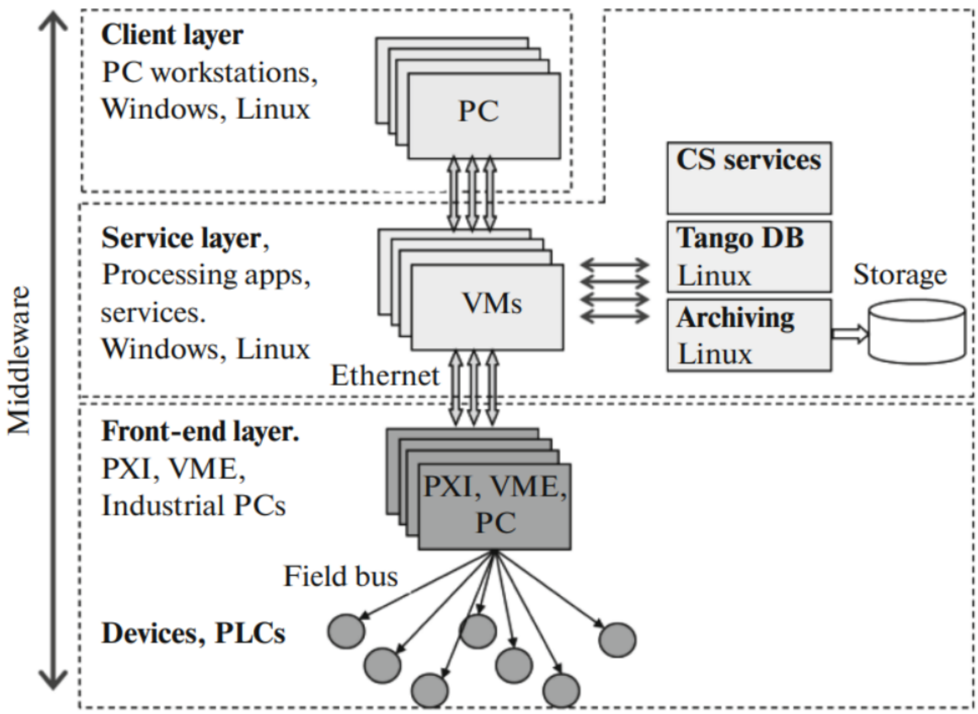
The DCS effectively monitors several critical external services to ensure the smooth operation of the experimental environment. These services include:

- Electricity Supply
- Backup Power Systems
- Temperature Levels
- Humidity Levels
- Radiation Levels

The DCS ensures the continuous monitoring of these vital parameters, contributing to the overall safety and stability of the experiment facility.

12. Control System of BM@N DCS

The Detector Control System (DCS) encompasses a range of pivotal functionalities that contribute to the seamless operation of the experiment. It provides comprehensive supervision, ensuring that all states of the experiment's subsystems are visible to shifters through a web application interface. Control mechanisms are facilitated through various graphical user applications (GUI apps), enabling shifters to efficiently manage and regulate subsystems. While no specific administrative functions or access control functionalities are mentioned, the DCS operates under different modes, with sub-detector states being localized for tailored status information. Notably, specialized automation includes the implementation of a control loop to regulate the temperature of front-end chips, which automatically cuts off low voltage if the temperature exceeds a threshold. The DCS employs a graphical representation for alarms, with different colors denoting distinct conditions. The number of alarms lies in the hundreds, spanning scenarios from hardware disconnection to voltage operations. In case of alarm-triggered emergency situations, shift leaders play a central role in providing guidance and directives for effective resolution.



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

(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.

13. General standards used for DCS

Detector Control Systems (DCS) in experimental physics typically adhere to certain general standards to ensure effective operation, safety, and data integrity. The standards may vary based on the specific experiment, the technologies involved, and the collaboration's preferences.

- Hardware Standards
- Software Standards
- Data Standards
- Safety Standards
- Document Standards
- Collaboration and Interoperability

⇒ **Hardware Standards:**

- Communication Protocols: Standardized communication protocols, such as Ethernet, USB, or custom protocols based on the requirements of the experiment.
- Data Acquisition Standards: Depending on the experiment, there might be specific standards for data acquisition systems, such as VME (Versa Module Eurocard), PCI (Peripheral Component Interconnect), or more modern standards like PCIe (PCI Express).

⇒ **Software Standards:**

- Control System Frameworks: Many experimental setups use control system frameworks such as EPICS (Experimental Physics and Industrial Control System) or TANGO Controls. These frameworks provide a structure for developing distributed control systems.
- Programming Languages: Commonly used programming languages include C/C++, Python, and Java.
- Middleware: Middleware technologies like CORBA (Common Object Request Broker Architecture) or ZeroMQ might be employed for communication between different components.

⇒ **Data Standards:**

- Data Formats: Standardized data formats for storage and exchange of experimental data. Common formats include ROOT, HDF5, or specific formats developed for the experiment.

⇒ **Safety Standards:**

- Interlocks and Safety Systems: Detectors are often integrated into safety systems to ensure that experiments can be conducted safely. Safety standards for interlocks and emergency shutdown systems are crucial.

⇒ **Documentation Standards:**

- Documentation Practices: Clear documentation of the control system architecture, software interfaces, and hardware specifications is essential. This helps in understanding, maintaining, and upgrading the system.

⇒ **Collaboration and Interoperability:**

• Interoperability Standards: Standards that facilitate collaboration and interoperability between different experiments or facilities. This is important in cases where multiple experiments share resources or collaborate on certain aspects.

14. Different standards considered for DCS

Several international standards are commonly used in the design and implementation of Distributed Control Systems (DCS). These standards help ensure interoperability, reliability, and safety in industrial and scientific environments.

1. ISA (International Society of Automation)
2. ISO (International Organization for Standardization)
3. IEC (International Electrotechnical Commission)

1. ISA (International Society of Automation):

- ISA is a global non-profit organization that develops and publishes standards for automation and control systems.
- ISA-5.1 Instrumentation Symbols and Identification: This standard establishes a system for the identification of instrumentation and control devices.

2. ISO (International Organization for Standardization):

- ISO develops and publishes international standards covering a wide range of industries.
- ISO 9001 Quality Management Systems: While not specific to control systems, ISO 9001 is a widely adopted standard for quality management, which could be relevant for ensuring the quality of control system processes.

3. IEC (International Electrotechnical Commission):

- IEC is an international standards organization specializing in electrotechnical standards.
- IEC 61131-3 - Industrial automation systems - Programmable controllers: This standard defines the programming languages and associated elements for programmable controllers used in industrial automation systems.

15. Comparison between ISO ISA and IES

ISO (International Organization for Standardization), ISA (International Society of Automation), and IEC (International Electrotechnical Commission) are three distinct organizations that develop and publish international standards. Each organization has its focus and scope, and they collaborate on some standards. Here's a brief comparison:

1. ISO (International Organization for Standardization):

- Focus: ISO is a global body that develops and publishes international standards across various industries, including manufacturing, technology, healthcare, and more.
- Scope: ISO standards cover a broad range of topics, and they are not limited to specific sectors or industries.
- Example Standard: ISO 9001 for Quality Management Systems is a widely known ISO standard.

2. ISA (International Society of Automation):

- Focus: ISA primarily focuses on standards related to automation and control systems. It plays a key role in the development of standards for industrial automation and instrumentation.
- Scope: ISA standards are often specific to the field of automation, covering topics such as process control, safety systems, and industrial cybersecurity.
- Example Standard: ISA-88 for Batch Control Systems provides guidelines for the design and operation of batch processes.

3. IEC (International Electrotechnical Commission):

- Focus: IEC is a global organization that develops and publishes international standards for all electrical, electronic, and related technologies, including power generation, transmission, and distribution.
- Scope: IEC standards cover a wide range of electrical and electronic technologies, from consumer electronics to industrial automation.
- Example Standard: IEC 61131-3 for Programmable Controllers is a standard for the programming languages used in programmable logic controllers (PLCs).

In summary:

- ISO covers a wide range of industries and sectors with a broad scope of standards.
- ISA specializes in standards related to automation and control systems, especially in industrial settings.
- IEC focuses on standards for electrical and electronic technologies

16. Different standards considered for the DCS

Based on the understanding of the different international standards, some of the standards were studied into detail and analysed further to obtain ore data about it.

1. **ISA 88**

• ISA-88, also known as the ISA-88 Batch Control Systems standard, is a widely recognized standard developed by the International Society of Automation (ISA). The full title of the standard is "ISA-88: Batch Control Part 1: Models and Terminology" and it's part of the ISA-88 series.

This series provides guidelines for the design and implementation of batch control systems in manufacturing.
• The ISA-88 standard defines models and terminology for batch control systems, providing a common framework and language for the design and operation of batch processes. It establishes standards for the structure of batch control systems and defines concepts such as:
• Physical Model: Describes the physical equipment and devices involved in a batch process.
• Procedural Model: Describes the procedures followed in a batch process, including recipes and recipes management.
• Coordination Model: Describes the coordination between different elements of the batch process.
• The standard aims to improve communication and understanding between manufacturers, system integrators, and suppliers involved in batch manufacturing processes. It provides a foundation for the development of batch control systems and helps ensure consistency and interoperability.

2. **ISA 95**

• ISA-95, also known as ANSI/ISA-95 or ISA-95.00.01, is a standard for enterprise and control systems integration developed by the International Society of Automation (ISA). Its full title is "Enterprise-Control System Integration - Part 1: Models and Terminology."
• ISA-95 provides a framework for integrating enterprise and control systems, aiming to standardize the integration of business systems (such as Enterprise Resource Planning - ERP) with manufacturing and control systems. The standard defines models and terminology that facilitate communication and understanding between different levels of an organization.

The key parts of ISA-95 include:

Part 1 - Models and Terminology: This part establishes the concepts, models, and terminology for the integration of enterprise and control systems.

Part 2 - Object Models and Attributes for Manufacturing Operations Management: This part focuses on object models and attributes for various aspects of manufacturing operations.

Part 3 - Models of Manufacturing Operations Management: This part provides models for the integration of manufacturing operations with the business systems.

- ISA-95 is particularly relevant in industries where the integration of information technology (IT) systems with industrial automation and control systems is crucial for achieving efficient and effective operations. It helps define a common language and understanding between different stakeholders in an organization, such as operations, IT, and management.

3. ISA 99

- ISA-99, also known as ANSI/ISA-99 or ISA-99.00.01, is a standard developed by the International Society of Automation (ISA) titled "Industrial Automation and Control Systems Security." This standard is more commonly known as ISA-99 or ISA/IEC 62443. The full title of the standard is "ISA-99.00.01-2007 - Security for Industrial Automation and Control Systems: Concepts, Terminology, and Models."
- ISA-99 focuses on the security of Industrial Automation and Control Systems (IACS) to address the unique challenges and requirements in industrial settings. It provides a framework and guidelines for implementing security measures to protect critical infrastructure from cyber threats. The standard defines concepts, terminology, and models related to industrial automation and control systems security.

Key components and parts of ISA-99 include:

Part 1: Concepts and Models: Establishes terminology and models for the description of industrial automation and control system security concepts.

Part 2: Policies and Procedures: Provides guidelines for developing security policies and procedures specific to industrial automation and control systems.

Part 3: System Security Requirements and Security Levels: Focuses on defining security requirements and security levels for industrial automation and control systems.

Part 4: Secure Product Development Life-Cycle Requirements: Addresses the security aspects throughout the development life cycle of industrial automation and control system products.

Part 5: Security for Process Automation Systems: Specifically addresses security considerations for process automation systems.

- ISA-99 is widely recognized and used in industries where securing industrial control systems is critical, such as in manufacturing, energy, and other critical infrastructure sectors.

17. System Standards and Comparison Parameters

Some of the system standards and parameters were considered to be studied more into the core to find out any analysable and comparable parameters present within them to contribute towards the manuscript preparation.

1. ISO/IEC 15288 Systems and software engineering System life cycle processes

ISO/IEC 15288 is an international standard that provides a framework for describing the life cycle processes of systems and software engineering. When comparing systems based on ISO/IEC 15288, you can consider various parameters to assess their performance, capabilities, and overall adherence to the standard.

Parameters for comparison

- Flowsheet for the system
- Architectural details for each equipment involved
- Efficiency of System Design and its effectiveness
- Methodologies used in the process
- Version updates
- Configuration and Setup
- Risk identification and Crisis assessment
- Quality Control and Assurance Standards
- Life Cycle Model assessment
- Documentation and User Manuals Present
- System Independence

2. ISO/IEC 12207 Systems and software engineering Software life cycle processes

ISO/IEC 12207 is an international standard that defines the processes of the software life cycle. When comparing systems based on ISO/IEC 12207, you can consider various parameters to assess their software development and maintenance processes.

Parameters for comparison

- Experiment Costs and Schedule
- Software used and standards
- Coding and standards associated
- Software versions
- Any improvements or updates like bug fixes
- Data protection, encryption and access control
- Changes in the scale of operation of software

3. ISO 15745 Industrial automation systems and integration

ISO 15745 addresses industrial automation systems and integration, providing guidelines for developing and representing systems in a standardized manner. When comparing systems based on ISO 15745, you can consider various parameters to assess their performance, interoperability, and overall effectiveness.

Parameters for comparison

- System compatibility
- Integrated devices
- Number of devices independent and integrated
- Replaced devices
- Data representation formats
- Third party apps or systems used
- Demands and requirements met
- System safety and security
- Tools and Interfaces
- Lifecycle of automation system – maintenance updates and upgrades
- Availability of user manuals, technical documentation, and system architecture documents
- Alarms

4. **IEC 61850 Communication networks and systems for power utility automation**

IEC 61850 is an international standard that defines the communication protocols and system requirements for the automation of power utility systems. When comparing systems based on IEC 61850, you can consider various parameters to assess their performance, interoperability, and overall effectiveness in power utility automation.

Parameters for comparison

- Support systems engaged
- Integrated energy devices present and their function
- Data modelling tool used
- Cybersecurity measures taken
- Configuration tools used
- SCADA system integration tools
- Information exchange

5. **ISA-101 - Human-Machine Interfaces for Process Automation Systems**

ISA-101, also known as ANSI/ISA-101, is a standard that provides guidelines for the design and implementation of Human-Machine Interfaces (HMIs) for process automation systems. When comparing process automation systems based on ISA-101, you can consider various parameters related to HMI design and functionality.

Parameters for comparison

- Compare graphical elements used in HMI
- Alarms present, representation, and response mechanisms
- Navigation and interaction design
- Colour conventions and use
- Level of standardization of HMI use (layout, graphics, navigation elements)

- Information presented on the HMI screens
- Trend displays
- Use of interactive elements such as buttons, sliders, and pop-ups
- Data logging and reporting features integration into the HMI
- HMI supporting multiple displays and screen arrangements
- HMI integration with other systems, such as control systems and databases.

6. ISA-18.2 - Management of Alarm Systems for the Process Industries

ISA-18.2, also known as ANSI/ISA-18.2, is a standard that provides guidelines for the management of alarm systems in the process industries. When comparing process systems based on ISA-18.2, you can consider various parameters related to alarm design, implementation, and management.

Parameters for comparison

- Alarm priorities, limits, and setpoints.
- Processes and methodologies for alarm rationalization
- Design and presentation of alarms in the HMI.
- Alarm suppression is handled in each system
- System adaptation to dynamic process conditions.
- System management of alarm floods and multiple simultaneous alarms.
- Dead time is considered in alarm management.
- Alarm performance metrics.
- Audit trail for alarm-related activities
- Alarm management system integrated with HMI and control systems.

7. IEC 62682 - Data structures and elements in process equipment catalogues

IEC 62682 is a standard that provides guidelines for the representation of data structures and elements in process equipment catalogues in the context of industrial-process measurement and control. When comparing systems or processes based on IEC 62682, you can consider various parameters related to the application of Data structures and elements in process equipment catalogues.

Parameters for comparison

- Data structures are represented
- Individual elements within the catalogues
- Data exchange formats
- Compare the types of data supported
- Catalogues integrated with control systems.
- Completeness and clarity of documentation for systems
- Versioning and compatibility issues
- Security measures implemented
- Processes for validating data
- Data Accessibility

8. IEC 61882 - Hazard and operability studies (HAZOP studies)

IEC 61882 is an international standard that provides guidelines for conducting Hazard and Operability Studies (HAZOP studies). These studies are a systematic and structured approach to identifying potential hazards and operability issues in industrial processes. When comparing systems or processes based on IEC 61882, you can consider various parameters related to the application and effectiveness of HAZOP studies.

Parameters for comparison

- Methodologies employed
- Composition of team
- No of process nodes or elements
- Critical parameters such as temperature, pressure, flow, and composition are adequately addressed
- Deviations from normal operating conditions
- Severity of identified deviations.
- Risk ranking of identified deviations

18. Data table of BM@N for the Comparative study of ALICE and BMAN experiment

The table provided below shows a list of the comparable parameters that could be used for the comparison between the different sections of the BM@N and ALICE, which could contribute positively to the future manuscript preparation.

Comparative Study of the DCS of ALICE and BM@N			
BM@N DCS Checklist			
S No.	Questions	Answers Provided	
	Publications regarding the BM@N DCS	2 additional publ . запросить по е mail	
1	Design Documentation regarding the DCS for the BM@N Experiment (like CDR, TDR, etc.)	try to colect to wiki. but now empty	
2	Deployment Diagrams and control system layout		
3	System Layout of the DCS (Decomposition style)	decomposition similar to cern but no ECS; autonomous entity with Data Acquisition (DAQ) system and the Trigger System function	
4	Hardware List (total number of hardware the DCS is connected to)		
	- number of detectors involved in the BM@N experiment	10 detectors but not all connected to the DCS, some have there own localised control system and run independently taking only minor feedbacks from the DCS	
	- number of crates	8	
	- number of embedded computers or network devices	54 (Network Devices)	
	- number of control computers or servers	2 servers, one main and one reserve	
	- number of SCADA systems	only TangoControl (Sole SCADA system employed)	
	- subsystems number	can calculate later	
	- front-end services	can calculate later	
	- rough number of the PLC's	0	
	- measured parameters number	later	DCS Decomposition Style
**	Number of external Services Monitered by the DCS	- Electricity Supply - Backup Power Systems - Temperature Levels - Humidity Levels - Radiation Levels	
	-		
	-		

5	Software Composition		
	- type of SCADA system used	tango	Data Flow Diagram
	- any specific framework which are used?	PyTango- framwork fro python, used in development, PySide for gui of DCS	
	- anyother application software used?	CAEN Crate control is done through gecko and an inhouse developed applications	instead of a data proessing farm, there is one data server to process data from all the hardware
	- how was the scada implementation with hardware done? connection protocols	MODBUS TCP, SNMP, socket interfaces, opcua,	storage, offline and online present
	- developing studio used for PLC? (as tango dose not support feild level control)	no plcs as digital detector signals are given by the feild level electronics and subsystems	online - postgreSQL
	- any documents to refer to better understand the software structure of the DCS?	yes	offline - taken from the online database cluster based on postgreSQL
6	Process of system testing and comissioning and the changes made after the first run (if any)	System testing is done with all the detector gorups in test tents before 2-3 months before the first run, changes... for monitoring and control desktop application was made to web applicaton now, added several new applications for control the subsyestems instead of just one like in the first run	
7	What are the functionalities of the DCS?		
	- supervision	yes, all the experiment subsystem states are visible to the shifters in the web application	
	- control	control is through several gu apps to control the subsystmes by the shifters	GUI Example
	- administrative functions	no	
	- access	no	
	- system configuration	no	
8	What types of automation functions you realised		
	- blocks		
	- interlock		
	- control loop (regulation and feedback)	only the temp of FE chips is high the lv cut off, made using sub tango servers which are specialised for the task	
	- what are the different operation modes of the DCS	status is localised for sub detectors	
	- step programs	none	
9	How many automation functions you realised in numbers	DCS DAQ Trigger system	

10	Numbers of alarm in order of 100s or 1000s?	100s	
	- alarm boards and tables	completely graphical, red - the chamber of detector is tripped from caen crate, orange - channels of powersupply is over voltage, purple - harware is not connected, green - all okay, white - hwen hardware is off (no power supply), grey - the equipment is not connected for a long time (not in the hall), yellow - wrap up or wrap down voltage	
	- alarm classes and groups	class are there, disconnection of hardware -- disable state, power classes. groups of alarms are absent	
	- alarm hysteresis	no	
	- alarm engage	no	
	- alarm in emergeny situation, posible solutions	shift leader will hep with orders to resolve the alarm	
11	DCS Dataflow		
	- data flow diagram		
	- data amount in each run handled by the DCS (rough average)	5mil events total experminet part of the DAQ servers, 50gb of slow control data. (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)	
	- types of databases (archival database, configuration database, conditions database)	3 database servers, acts as a backup for other servers also , one archive data, 2 for reading data graphane fro example	
12	User interface of the BM@N DCS, pls do provide examples of screenshots of GUI of the DCS during operation		
	- hirearchy of pannels	yes, but can be navigated to other sub detector systems from the main pannel	
	- navigation	yes from the main pannel	
	- passportization of object, labeling (faceplates)	not present	
	- denominization of symbols	green to red incase of error	
	- types of information displayed on the main DCS screen	take from the ss	
	- UI configuration based on users	nope, based on a group of users and not for individuals	
13	Operating software used	linux debian based - for tango control system, web applications can be run in any OS	
14	Organizational Structure during shift	YES BUT Complicated Refer doc	
	- types of shifters (shift leader, shadow shifters, etc)	one shift leader for every subdetector shift in every day, one main shift leader in every shift, DCS workstations number to be mentioned later	
	- number of shifters in one run working for the DCS		

15	Standarizaton used		No standardization	
16	Number of Environmental Parameters Used		9	
	-Parameters Considered		Humidity Temperature Pressure Magnetic Field Beam Pipe pressure Profilometer Targets	
17	International standards that can be taken up for comparison			
1	**From**	**IEC 61882 - Hazard and operability studies (HAZOP studies)**		
	1	Different Methodologies used and its number		
	2	Composition of team, its decomposition and quantitative analysis		
	3	No of process nodes or elements from the setup		
	4	Usage of Critical parameters such as temperature, pressure, flow, and composition		
	5	Deviations or variations (including errors, bug fixes, updates) from normal operating conditions		
	6	Severity of identified deviations, frequency and number of identified deviations		
	7	Risk ranking of identified deviations based on hazard level		
2	**From**	**IEC 62682 - Data structures and elements in process equipment catalogues**		
	8	Data structures - Number, representation and denotions		
	9	Individual elements within the catalogues		
	10	Format of Data exchange		
	11	Types of Data supported		
	12	Catalogues - types and numbers, integrated with control systems.		
	13	Completeness and clarity of documentation for systems		

	14	Versions present for the setup and its compatibility issues, mitigation, etc.		
	15	Security measures implemented		
	16	Processes for validating data and accessing them		
	17	Data Accessibility the type of file and formats saved and security		
3	**From**	**ISA-18.2 - Management of Alarm Systems for the Process Industries**		
		Alarm priorities, limits, and setpoints boundary conditions		
		Processes and methodologies for alarm rationalization		
		Design and presentation of alarms in the HMI.		
		Alarm suppression handled by each system		
		System adaptation to dynamic process conditions - changes to be recorded		
		System management of alarm floods and multiple simultaneous alarms.		
		Dead time in alarm management.		
		Alarm performance metrics.		
		Audit trail for alarm-related activities		
		Alarm management system integrated with HMI and control systems.		
4	**From**	**ISA-101 - Human-Machine Interfaces for Process Automation Systems**		
		Compare graphical elements used in HMI		
		Alarms present, representation, and response mechanisms		
		Navigation and interaction design		

		Colour conventions and use											
		Level of standardization of HMI use (layout, graphics, navigation elements)											
		Information presented on the HMI screens											
		Trend displays											
		Use of interactive elements such as buttons, sliders, and pop-ups											
		Data logging and reporting features integration into the HMI											
		HMI supporting multiple displays and screen arrangements											
		HMI integration with other systems, such as control systems and databases.											
5	**From**	**IEC 61850 Communication networks and systems for power utility automation**											
		Support systems engaged											
		Integrated energy devices present and their function											
		Data modelling tool used											
		Cybersecurity measures taken											
		Configuration tools used											
		SCADA system integration tools											
		Information exchange											
6	**From**	**ISO 15745 Industrial automation systems and integration**											
		System compatibility											
		Integrated devices											
		Number of devices independent and integrated											

		Replaced devices											
		Data representation formats											
		Third party apps or systems used											
		Demands and requirements met											
		System safety and security											
		Tools and Interfaces											
		Lifecycle of automation system – maintenance updates and upgrades											
		Availability of user manuals, technical documentation, and system architecture documents											
		Alarms											
7	**From**	**ISO/IEC 12207 Systems and software engineering Software life cycle processes**											
		Experiment Costs and Schedule											
		Software used and standards											
		Coding and standards associated											
		Software versions											
		Any improvements or updates like bug fixes											
		Data protection, encryption and access control											
		Changes in the scale of operation of software											
8	**From**	**ISO/IEC 15288 Systems and software engineering System life cycle processes**											
		Flowsheet for the system											
		Architectural details for each equipment involved											
		Efficiency of System Design and its effectiveness											

		Methodologies used in the process											
		Version updates											
		Configuration and Setup											
		Risk identification and Crisis assessment											
		Quality Control and Assurance Standards											
		Life Cycle Model assessment											
		Documentation and User Manuals Present											
		System Independence											

19. Future Work

The future work of this project includes classifying and analysing the parameters found from the data and literature search, which are then to be compiled and incorporated, after various updates into the data sheet for progressing the manuscript preparation. The qualitative and quantitative data, whichever was found during the search was also added to the document. It is to be further modified, cross checked and validated in due time. The manuscript preparation is currently under progress.

20. Conclusion

The project involved a deep analysis of both the BM@N experiment from JINR and ALICE experiment at CERN. The comparison between both the projects were done and in the process, when indulging more into the basics of BM@N, we seem to find out a lot of interesting data from various sources, regarding the BM@N experiment. There are actually a whole lot of parameters that were newly discovered which could be of additional support towards the preparation of the manuscript positively.

21. Acknowledgements

Last but not the least, an insightful understanding of BM@N was achieved and I would like to thank Prof. Nikita Baldin, for guiding me throughout the project and helping me understand and complete the tasks in time. Your support and guidance helped me to undertake this project with great enthusiasm and understand greatly about the control systems at JINR.