MEXnICA, Mexican group in the MPD-NICA experiment at JINR

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Abstract. The Nuclotron Ion Collider fAcility (NICA) accelerator complex is currently under construction at the Joint Institute for Nuclear Research (JINR) laboratory located in the city of Dubna in the Russian Federation. The main goal of NICA is to collide heavy ion nuclei to study the properties of the phase diagram of strongly interacting matter at high baryon density. In this accelerator complex, two big particle detectors are planned to be installed: Spin Physics Detector (SPD) and Multi-Purpose Detector (MPD). At the design luminosity, the event rate in the MPD interaction region is about 6 kHz; the total charged particle multiplicity would exceed 1000 in the most central Au+Au collisions at $\sqrt{s_{NN}} = 11$ GeV.

Since the middle of 2016 a group of researchers and students from Mexican institutions was formed (MEXnICA). The main goal of the MEXnICA group is to collaborate in the experimental efforts of MPD-NICA proposing a BEam-BEam counter detector which we called BEBE. In this written general aspects of MPD-NICA detector and BEBE are discussed. This material was shown in a contributed talk given at the XXXI Annual Meeting of the Mexican Division of Particles and Fields held in the Physics Department of CINVESTAV located in Mexico City during the last week of May 2017.

1. Introduction

Heavy-ion physics allow us to study the matter under extreme conditions of high temperature and energy density. The study of hot and dense baryonic matter should shed light on: in-medium properties of hadrons and the nuclear matter equation of state (EOS); the onset of deconfinement (OD) and/or chiral symmetry restoration (CSR); phase transition (PT), mixed phase and the critical end-point (CEP); possible local parity violation in strong interactions (LPV) [1].

Experimental evidences show that the deconfined phase of nuclear matter (Quark-Gluon Plasma, QGP) can be created in ultra-high-energy nuclear collisions [2]. In this type of collision, there are some signatures related with the production of QGP, i.e., collective flow, long-range angular correlations, suppression of hadrons with high transverse momentum ($p_T$) and enhancement of thermal photons and di-leptons. Theoretical calculations indicate that the deconfinement phase transition can be accomplished by partial restoration of the chiral symmetry in heavy-ion collisions leading to possible modifications of hadronic spectral functions in dense hadronic matter. RHIC experiments reported the observation of strong elliptic flow [3] and jet quenching (suppression of hadrons with large $p_T$) [4]. Recently, LHC experiments reported the observation of long-range, near-side angular correlations in Pb-Pb and p-Pb collisions [5].


addition to this result, it was found that the hot dense matter created in heavy-ion collisions behaves like a fluid with almost zero friction [6], which undoubtedly shows an advance in the understanding of this state of matter. Unexpected phenomena like the enhanced production of multi-strange hadrons in high-multiplicity p-p collisions (proton collisions exhibit similar patterns to those observed in heavy-ion collisions) [7] have also been reported. Figure 1 shows the covered region of the diagram phase of the QCD by current and future experimental facilities like NICA at JINR [8].

![Figure 1](image.png)

**Figure 1.** Diagram phase of the QCD. The energy range of NICA is an unexplored region to date. Experimental data on hadron production properties at SPS suggest that this transition occurs within the NICA energy range.

NICA is a new accelerator complex which will provide beams of ions over a wide range of atomic masses (from p to Au) at average luminosity of $10^{27} \text{ cm}^{-2}\text{s}^{-1}$ for gold-gold collisions and $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ for proton-proton collisions. The center-of-mass energy will be between 4 to 11 GeV for Au+Au and up to 27 GeV for p+p. The energy range of NICA will allow to study environments with high net baryon density where the onset of deconfinement phase transition could occur.

The physics tasks of the NICA heavy-ion program are:

- event-by-event fluctuation in hadron productions
- femtoscopic correlation
- directed and elliptic flows for various hadrons
- multi-strange hyperon production (including hypernuclei): yield and spectra
- photon and electron probes
- charge asymmetry

To achieve a successfully study of matter under extreme conditions, the experimental program of NICA will be performed with the Multi-Purpose Detector (MPD).

2. The Multi-Purpose Detector (MPD) at NICA
The Multi-Purpose Detector (MPD) [9] is an experimental complex to be located at one of the interaction points of the NICA collider, see figure 2. The MPD detector is composed by central and forward detectors designed to detect charged hadrons, electrons and photons that will be
produced in heavy-ion collisions at high luminosity in the energy range of the NICA collider. As the average transverse momentum of the particles produced in a collision at NICA energies is below 500 MeV/c, the detector design requires a very low material budget. The magnetic field produced by the MPD magnet will be of 0.6 Teslas. The general layout of the MPD apparatus is shown in figure 3.

Figure 2. Schematic view of NICA facilities. MPD will be located at point 8. Taken from [10]

Figure 3. Multi-Purpose Detector at NICA. The detector consist of three major parts: CD-central detector, and (FS-A, FS-B) - two forward spectrometers (optional). The following subsystems are drawn: superconductor solenoid (SC Coil) and magnet yoke, inner detector (IT), straw-tube tracker (ECT), time-projection chamber (TPC), time-of-flight system (TOF), electromagnetic calorimeter (EMC), fast forward detectors (FFD), and zero degree calorimeter (ZDC) [11].

The MPD physics program will be carried out in two stages.
(i) participant detectors: TPC, TOF, ECAL, ZDC and FD. To study:
- Particle yields and spectra (pions, Kaons, protons, etc)
- Event-by-event fluctuations
- Femtoscopy involving pions, Kaons and protons
- Collective flow for identified hadrons
- Electromagnetic probes (electrons, gammas)

(ii) participant detectors: TPC, TOF, ECAL, ZDC, FD + ITS. To study
- total particles multiplicities
- asymmetries studies (better reaction plane determination)
- di-lepton production
- charmonium production
- production of soft photons and hyper-nuclei

Considering the fact that after the collision of two heavy-ion nuclei the matter behaves as a thermalized system and the particle production tracing a trajectory on phase diagram, maybe close to the CEP; a key study is the event-by-event fluctuations of the physical observables of particles in its final state, and thus, a particle detector capable to give a trigger signal for heavy-ion collisions is crucial. In this sense, since the middle of 2016 a group of researches and students from Mexican institutions was formed (MEXnICA). The main goal of the MEXnICA group is to collaborate in the experimental efforts of MPD-NICA proposing a BEam-BEam counter detector which we called BEBE.

3. MEXnICA group
The institutions involved in the MEXnICA group are:
- **BUAP** (Benemérita Universidad Autónoma de Puebla): Facultad de Ciencias Físico Matemáticas
- **CINVESTAV** (Centro de Investigación y Estudios Avanzados del I.P.N.): Departamento de Física
- **UAS** (Universidad Autónoma de Sinaloa): Facultad de Ciencias Físico Matemáticas
- **UNISON** (Universidad de Sonora): Departamento de Física
- **UNAM** (Universidad Nacional Autónoma de México): Instituto de Ciencias Nucleares

The main goal of MEXnICA within MPD efforts is to contribute in the study of the QGP phase diagram from both, theoretical and experimental points of view in the search of the CEP:

(i) theoretical point of view
- to study the mechanism responsible for the restoration of chiral symmetry
- to study the QCD phase diagram at finite values of temperature and density

(ii) experimental point of view
- to study signatures that will allow to locate the CEP
- to study the inclusion of a detector that allows to MPD to increase its pseudo-rapidity coverage. With such detector, the MPD could increase its capabilities to determine the event plane resolution and trigger efficiency for general heavy-ion collisions and specific physical processes.
4. MEXnICA proposal

In collider experiments, the inclusion during commissioning or regular operations of a detector capable to monitor the beam activity is desirable. With the information provided with such kind of apparatus, it is possible to setup a trigger system to identify and to discriminate beam-beam minimum bias or centrality events from background and beam-gas interactions. In addition, these types of systems can be used for the reconstruction of physical observables of interest in heavy-ion collisions such as

- **multiplicity of charged particles:** key observable for the determination of the centrality of the collision events and the event plane resolution
- **luminosity measurement:** used to determine the absolute cross section of reaction processes

The technology and the type of materials for the development of beam monitors is diverse depending on their applications. In the specific case of particle detectors designed to collect information from colliders, it is often the use of materials and light sensors like diamond, silicon, quartz, plastic scintillator, MCTP, Si-PMT, APD and PMT.

Taking into consideration our previous experience on development of charge particle detectors [12, 13, 14], we propose a BEam-BEam counter detector (BEBE) for the MPD-NICA Project at JINR based on a granular plastic scintillator array and APD as light sensors.

As a first approach, the BEBE detector will consists of two detectors located at 2 meters away from the interaction point of the MPD-NICA, BEBE-1 and BEBE-2 respectively. Each detector is composed by an array of 80 cells made of plastic scintillator arranged in five rings forming a sixteen sectors disk of 1.52 meters of diameter (see figure 4). The pseudorapidity coverage of BEBE would be $1.69 < |\eta| < 4.36$.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{BEBE_detector_diagram.png}
\caption{Schematic of BEBE detector. It will consists of an array of 80 cells distributed in 5 concentric rings.}
\end{figure}

To carry out a physics performance study of the BEBE detector within the experimental conditions of NICA, we have developed a dedicated module in the offline framework of the experiment: MPD-ROOT [15]. The results of the activity of BEBE during Au+Au collisions simulations at $\sqrt{s_{NN}} = 11 \text{ GeV}$ is shown in figure 5. In figure 6, a correlation between the BEBE mean multiplicity and the impact parameter of the simulated collisions is shown. As can be seen, BEBE is sensitive to the heavy-ion collisions in several impact parameter bins. This
type of studies are important because the centrality of the collisions is an important property that can not be accessed directly from the NICA beam online information. Thus, BEBE will play a crucial role in the identification of events per centrality range.

![Figure 5. Monte Carlo hits of BEBE detector. The activity in each cell of the detector change with respect to the centrality of the collision, as expected.](image)

![Figure 6. Mean multiplicity in BEBE versus impact parameter.](image)

5. Conclusions
NICA has the potential for competitive research in the studies of dense baryonic matter. The MPD detector has many advantages and meets all the ambitious physics requirements for exploring the phase diagram of strongly interacting matter in a high track multiplicity environment. The MPD detector covers a large phase space; it is functional at high interaction rates; comprises high efficiency and excellent particle identification capabilities. MPD is based on recent detector developments and has comparatively reasonable cost.
MEXnICA group is currently working on the final design of BEBE. In parallel, several theoretical studies are being developed focused on MPD-NICA physics program. A niche of technological development will be explored by the MEXnICA group: construction of plastic scintillator and electronics acquisition system are activities that will be developed by MEXnICA group members once the BEBE geometry is defined.

**MEXnICA group members**

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