Status of the MPD experiment at NICA

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Abstract — The Multi-Purpose Detector (MPD) at the NICA facility in Dubna is undergoing its final phase of assembly and commissioning, with the first beams expected at the end of 2026. Covering the collision energy range $\sqrt{s_{NN}} = 2.4$–3.5 GeV in fixed-target mode and 4–11 GeV in collider mode, MPD will probe the region of the QCD phase diagram where a first-order phase transition and critical point may occur. Following the first NICA run in 2026, preparations for MPD data taking are ongoing. This report summarizes the current project status and recent feasibility studies of MPD physics performance.

1. INTRODUCTION

Relativistic heavy-ion collisions provide a unique tool for recreating, under controlled conditions, strongly interacting matter under extreme temperature and density. The conditions similar to those that existed in the early Universe microseconds after the Big Bang are reached in the collision-energy range available at the Large Hadron Collider (LHC) and at the top energies of the Relativistic Heavy Ion Collider (RHIC). At sufficiently high temperature and energy density, hadronic matter is expected to undergo a cross-over phase transition into a deconfined state of quarks and gluons, commonly referred to as quark–gluon matter (QGM). Experiments at RHIC and the LHC have established key properties of this strongly coupled matter, primarily in the region of the QCD phase diagram characterized by low net-baryon density. The NICA accelerator complex is designed to explore a distinct sector of the QCD phase diagram, corresponding to high baryon density and moderate temperatures [1, 2]. Such baryon density conditions are relevant to the matter in neutron star mergers. Some theoretical models predict that this region may host a first-order phase transition and a critical end-point (CEP). The detailed study of heavy ion collisions at NICA energies will provide an insight into the properties of nuclear matter under extreme con-

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ditions, the transition from hadronic matter to QGM, the collective dynamics of strongly interacting matter, and the restoration of chiral symmetry, a fundamental property of QCD.

2. NUCLOTRON-BASED ION COLLIDER FACILITY (NICA)

The NICA accelerator complex, located at the Veksler-Baldin Laboratory for High Energy Physics of JINR, includes a heavy-ion source, linear accelerator, booster synchrotron, Nuclotron superconducting synchrotron, and two collider rings [1]. The Nuclotron provides heavy-ion beams up to $6A$ GeV for isospin-symmetric nuclei. The first stage of the heavy-ion program uses xenon beams, with Xe+W fixed-target and Xe+Xe collider operation [3–5]. In 2026, the first NICA run achieved two stable xenon beams in the collider rings.

Extracted Nuclotron beams are used by the BM@N fixed-target experiment [6], while the NICA collider is designed for protons, light nuclei, and heavy ions up to xenon and bismuth. The main experimental areas are MPD for heavy-ion studies [3, 4, 7] and SPD for polarized proton and deuteron spin physics [8]. While the NICA collider operates in the energy range $\sqrt{s_{NN}} = 4$–11 GeV for heavy ions, the MPD experiment can also reach $\sqrt{s_{NN}} = 2.4$–3.5 GeV in fixed-target mode.

3. MULTI-PURPOSE DETECTOR (MPD) EXPERIMENT AT NICA

The MPD is a 4π spectrometer for heavy-ion studies at NICA in the high baryon-density region. Its first-stage configuration includes the TPC, TOF, ECal, FHCal, FFD, and a superconducting solenoid with an iron return yoke, providing tracking, particle identification, calorimetry, triggering, and event-plane measurements for the MPD physics program [3–5].

MPD can also operate in the fixed-target mode using a thin wire target of about 100 μm diameter, shifted by about 1.5 cm from the central beam line near the MPD barrel edge [9]. This mode covers $\sqrt{s_{NN}} = 2.4$–3.5 GeV and can compensate for early collider luminosity limitations, with rates mainly constrained by the data-acquisition bandwidth.

The first-stage MPD subsystems are now in final integration, commissioning, and calibration for initial physics running.

4. HIGHLIGHTS FROM THE FEASIBILITY STUDIES AT THE MPD EXPERIMENT

Recent feasibility studies demonstrate the strong potential of MPD for early heavy-ion measurements at NICA. Collider-mode simulations of Bi+Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV show that the first-stage detector can reconstruct and identify the main physics probes with the required performance [4]. The studies use modern event generators, GEANT4 transport through the full MPD geometry, and standard reconstruction [10, 11]. Detailed collider mode results are given in [3, 4]. The following highlights focus on fixed-target feasibility studies.

Fig. 1 shows p_{T} spectra of identified π^+, K^+, and protons in Xe + W collisions at $\sqrt{s_{\mathrm{NN}}} = 2.87$ GeV. Using TPC and TOF information, the reconstructed spectra agree well with UrQMD predictions [12, 13], confirming the charged-particle tracking and identification performance.

Figure 2 presents the directed (v_1) and elliptic (v_2) flow of π^+ mesons and protons in Xe + W and Xe + Xe collisions at $T = 2.5A$ GeV ($\sqrt{s_{\mathrm{NN}}} = 2.87$ GeV). The symmetric Xe + Xe system provides a reference for detector effects. Reconstructed v_1 and v_2 values agree with the UrQMD input, demonstrating the feasibility of flow measurements in fixed-target mode.

Figure 3 shows p_{T} spectra of weakly decaying Λ hyperons and K^0_S mesons in different centrality intervals. The collider-mode reconstruction procedure [4], adapted to the fixed-target geometry, preserves both spectral shapes and normalizations.

Figure 4 shows the invariant-mass fit and centrality dependence of global Λ polarization in Xe + W collisions at $\sqrt{s_{\mathrm{NN}}} = 2.87$ GeV. A custom afterburner was used to introduce the polarization signal, and the generalized invariant-mass fit method was applied as described in [14]. The reconstructed values reproduce the generated P_Λ signal.

Figure 5 shows p_{T} spectra of the $K^*(892)^0$ and $\phi(1020)$ resonances. The agreement between reconstructed spectra and UrQMD predictions indicates that the yield of the resonance particles can be measured at low p_{T} in different centrality intervals.

5. SUMMARY

The MPD experiment at NICA is close to the first data taking with the first-stage detector subsystems in final integration, commissioning, and calibration. The NICA energy range will provide access to the high-baryon-density region of the QCD phase diagram, where the properties of strongly interacting matter, possible signs of a first-order phase transition, and the critical end-point can be investigated.

Recent feasibility studies confirm that MPD can perform key measurements in both collider and fixed-target modes. In fixed-target Xe + W and Xe + Xe collisions, realistic simulations demonstrate reliable reconstruction of identified charged hadrons, collective flow, weakly decaying particles, global Λ polarization, and hadronic resonances. The good agreement between reconstructed observables and model input indicates that MPD is well prepared for the initial heavy-ion physics program at NICA.

ACKNOWLEDGMENTS

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Captions to the figures

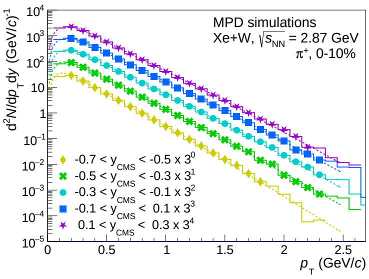
1. Transverse-momentum spectra of identified charged hadrons, π^+ (a), K^+ (b), and protons (c), reconstructed in Xe + W fixed-target collisions at $\sqrt{s_{\rm NN}} = 2.87$ GeV (markers) and compared with UrQMD model predictions (lines).

2. Directed flow v_1 (a–b) and elliptic flow v_2 (c–d) of π^+ mesons (a, c) and protons (b, d) in Xe + W (blue) and Xe + Xe (red) collisions at $T = 2.5A$ GeV ($\sqrt{s_{\rm NN}} = 2.87$ GeV). Results from realistic reconstruction (markers) are compared with UrQMD predictions (lines).

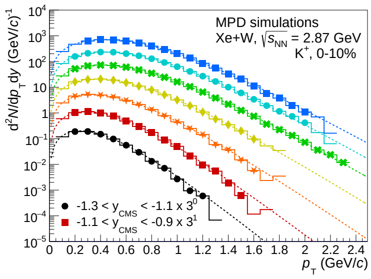
3. Transverse-momentum spectra of weakly decaying particles, Λ hyperons and K^0_S mesons, reconstructed in different centrality intervals (markers) and compared with generated distributions (lines).

4. Global Λ polarization in Xe + W collisions at $\sqrt{s_{\rm NN}} = 2.87$ GeV: invariant-mass fit example (a) and centrality dependence of P_Λ (b). The measured polarization from realistically reconstructed data (markers) is compared with generated data (lines).

5. Transverse-momentum spectra of $K^*(892)^0$ and $\phi(1020)$ resonances reconstructed in different centrality intervals and compared with UrQMD model predictions. Results from reconstructed data are shown with markers, while the generated signal is shown with lines.



(a)



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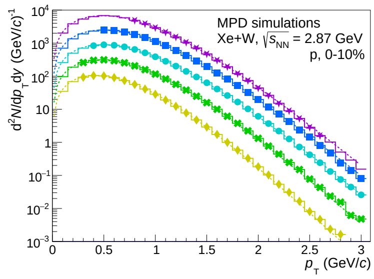
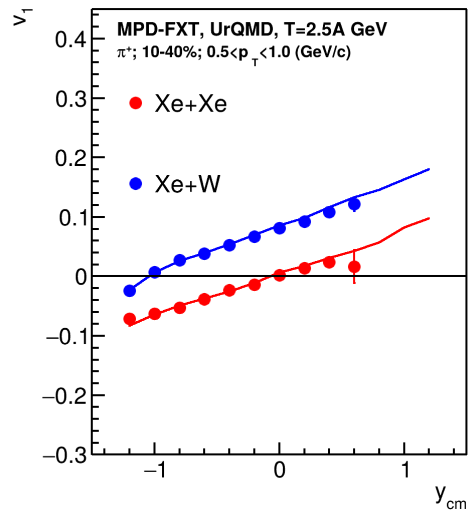
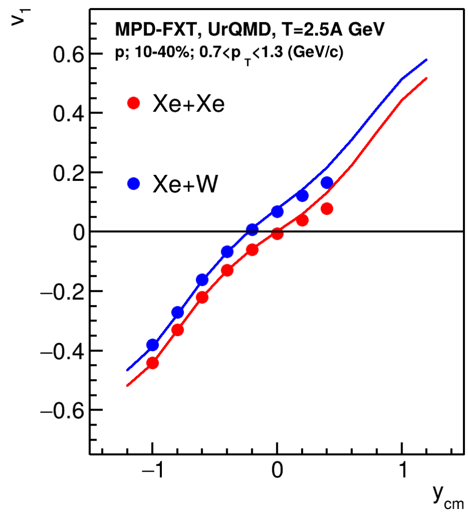


(c)

Figure 1.



(a)



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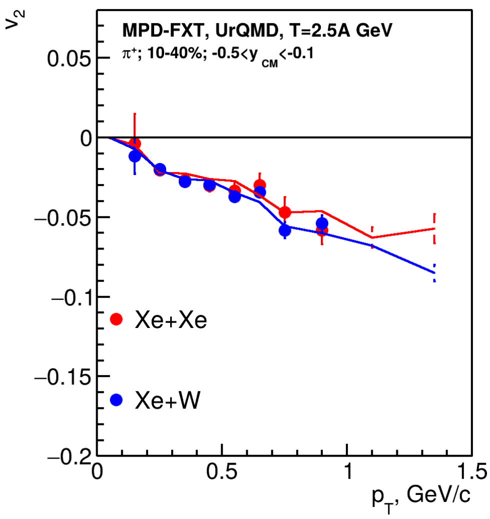

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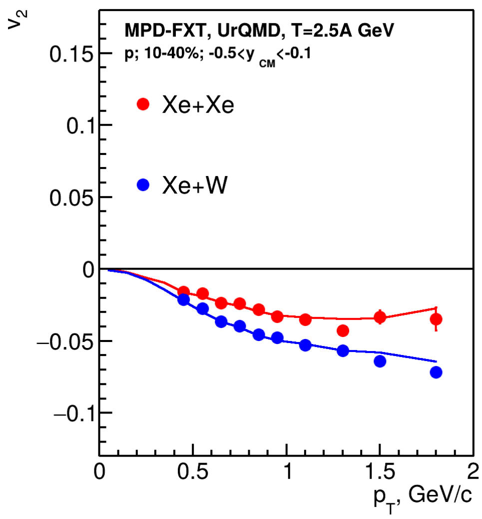
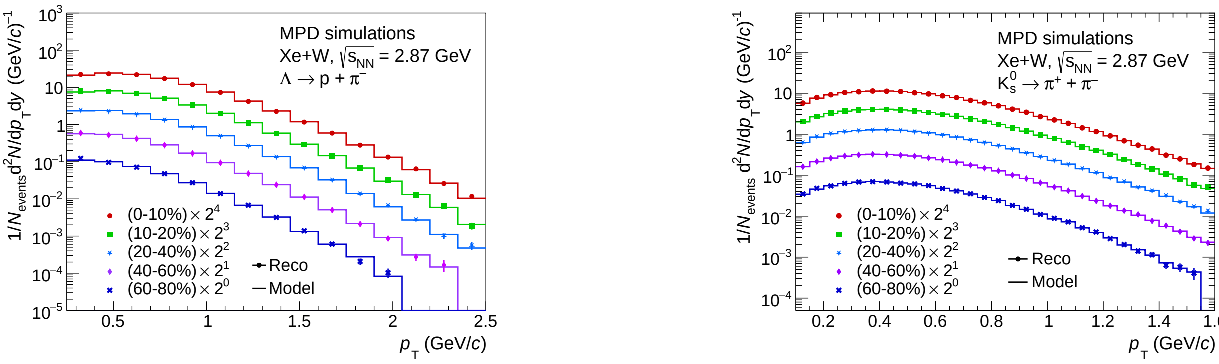


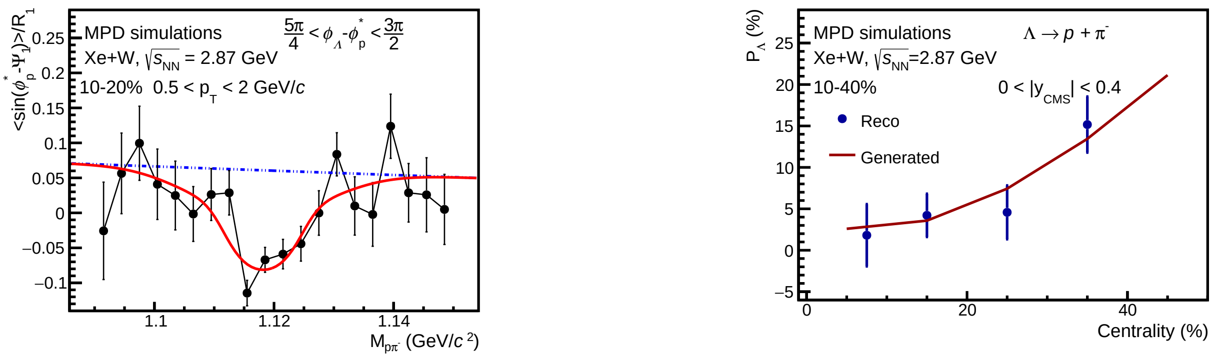
(d)

Figure 2.



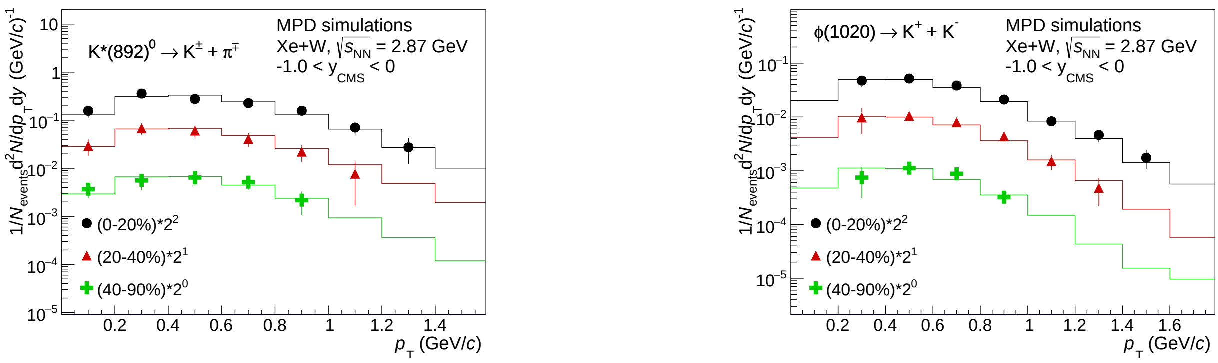
(a) (b)

Figure 3.



(a) (b)

Figure 4.



(a) (b)

Figure 5.