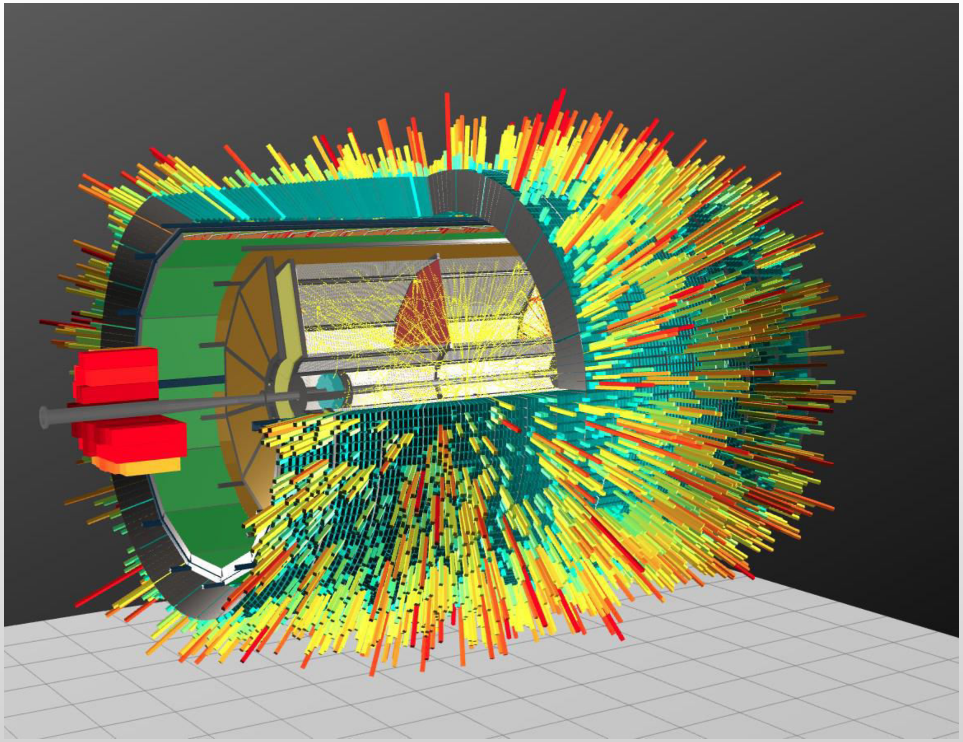
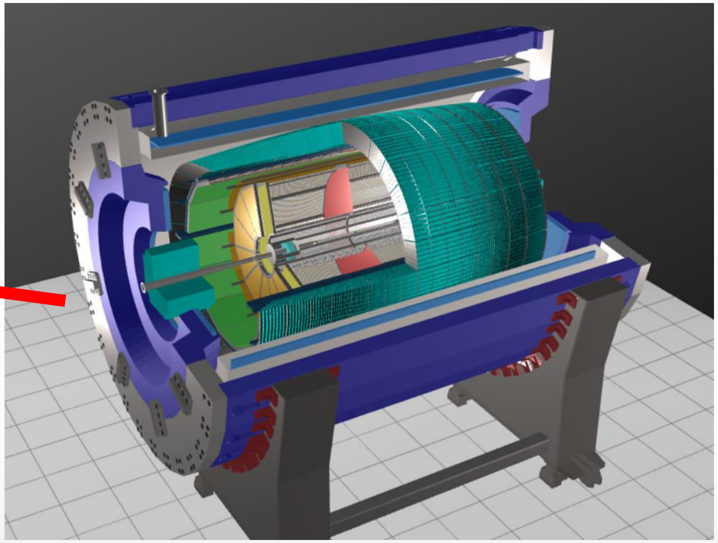
Статус эксперимента MPD и возможные задачи для ВШЭ

В.Г. Рябов (MPD Collaboration)



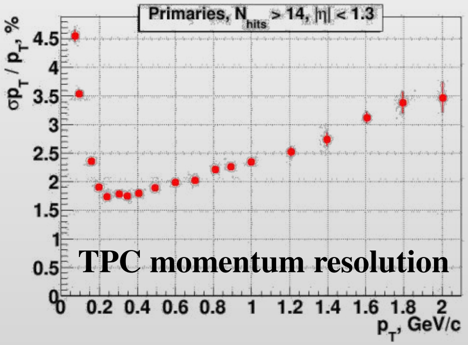
MPD @ NICA

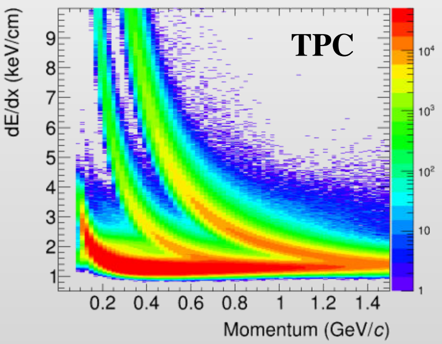
- One of two experiments at NICA collider to study heavy-ion collisions at $\sqrt{s_{NN}}$= 4−11 GeV

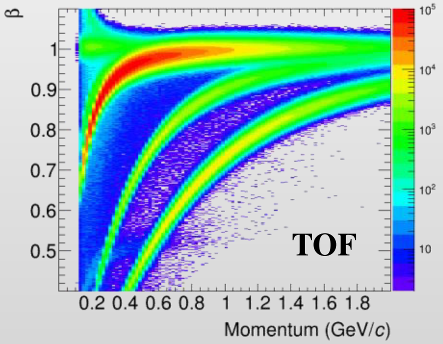


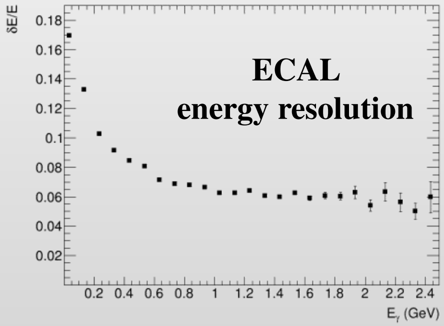
TPC: |Δφ| < 2π, |η| ≤ 1.6; **TOF, EMC**: |Δφ| < 2π, |η| ≤ 1.4; **FFD**: |Δφ| < 2π, 2.9 < |η| < 3.3; **FHCAL**: |Δφ| < 2π, 2 < |η| < 5

Au+Au @ 11 GeV (UrQMD + full chain reconstruction)



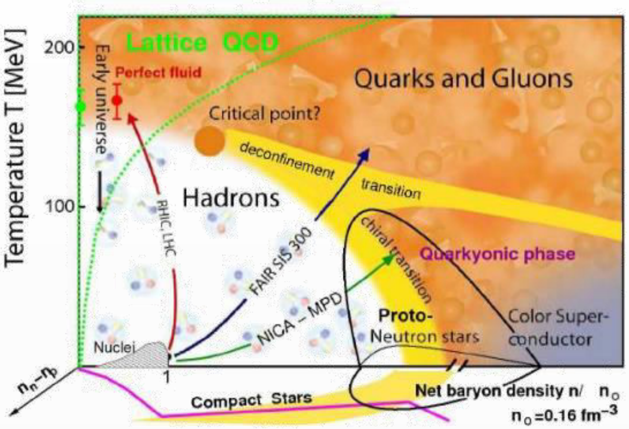




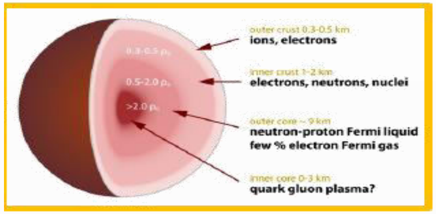


Heavy-ion collisions at NICA

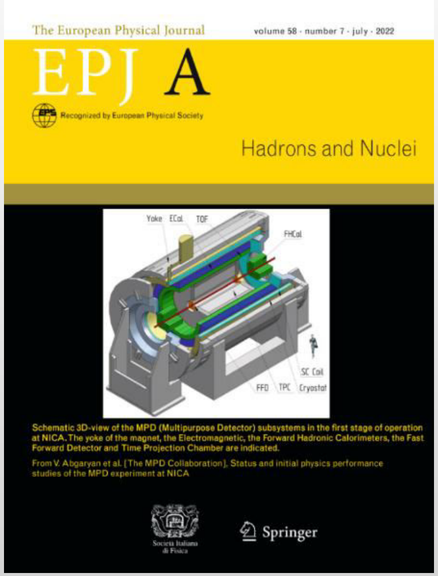
- Explore the QCD phase diagram, search for the phase transition and CEP at maximum baryon density



High baryon density:
Inner structure of
compact stars



Status and initial physics performance studies of the MPD experiment at NICA
Eur.Phys.J.A 58 (2022) 7, 140



The European Physical Journal
volume 58 · number 7 · july · 2022

EPJ A

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Hadrons and Nuclei

Schematic 3D-view of the MPD (Multipurpose Detector) subsystems in the first stage of operation at NICA. The yoke of the magnet, the Electromagnetic, the Forward Hadronic Calorimeters, the Fast Forward Detector and Time Projection Chamber are indicated.

From V. Abgaryan et al. [The MPD Collaboration], Status and initial physics performance studies of the MPD experiment at NICA

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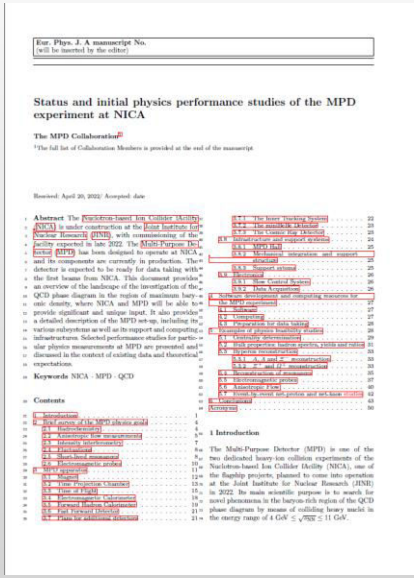


Eur. Phys. J. A manuscript No.
(will be inserted by the editor)

Status and initial physics performance studies of the MPD experiment at NICA

The MPD Collaboration[1]

[1]The full list of Collaboration Members is provided at the end of the manuscript

Received: April 20, 2022/ Accepted: date

Abstract The Nuclotron-based Ion Collider fAcility (NICA) is under construction at the Joint Institute for Nuclear Research (JINR), with commissioning of the facility expected in late 2022. The Multi-Purpose Detector (MPD) has been designed to operate at NICA and its components are currently in production. The detector is expected to be ready for data taking with the first beams from NICA. This document provides an overview of the landscape of the investigation of the QCD phase diagram in the region of maximum baryonic density, where NICA and MPD will be able to provide significant and unique input. It also provides a detailed description of the MPD set-up, including its various subsystems as well as its support and computing infrastructures. Selected performance studies for particular physics measurements at MPD are presented and discussed in the context of existing data and theoretical expectations.

Keywords NICA · MPD · QCD

Contents

1 Introduction

The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects, planned to come into operation at the Joint Institute for Nuclear Research (JINR) in 2022. Its main scientific purpose is to search for novel phenomena in the baryon-rich region of the QCD phase diagram by means of colliding heavy nuclei in the energy range of 4 GeV $\leq \sqrt{s_{NN}} \leq$ 11 GeV.

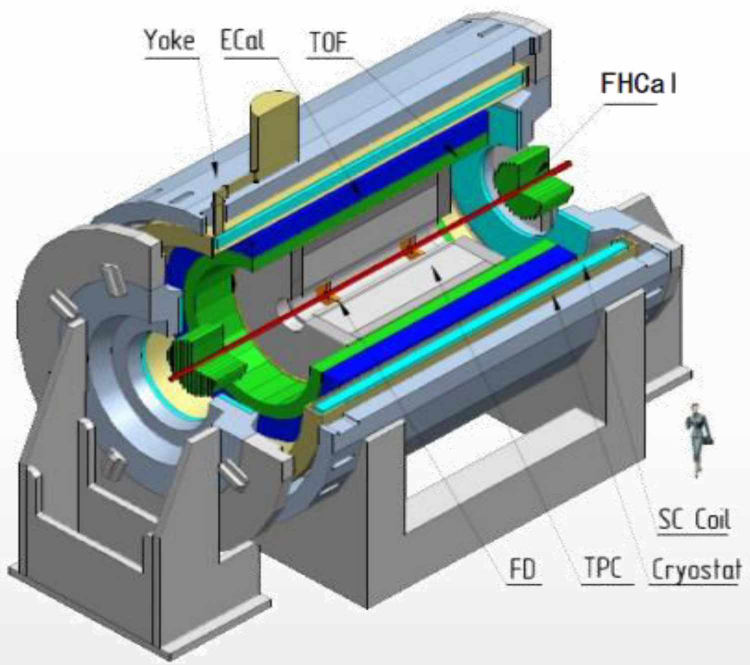
Multi-Purpose Detector (MPD) Collaboration

MPD** International Collaboration was established in **2018
to construct, commission and operate the detector

12** Countries, **>500** participants, **38** Institutes and **JINR

Organization

Acting Spokesperson: ***Victor Riabov***
Deputy Spokespersons: ***Zebo Tang, Arkadiy Taranenko***
Institutional Board Chair: ***Alejandro Ayala***
Project Manager: ***Slava Golovatyuk***



***Joint Institute for Nuclear Research, Dubna**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*SSI “Joint Institute for Energy and Nuclear Research – Sosny” of the National Academy of Sciences of Belarus, Minsk, **Belarus***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*University of Science and Technology of China, Hefei, **China**;*
*Huzhou University, Huzhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*University of Chinese Academy of Sciences, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Institute of Physics and Technology, Almaty, **Kazakhstan**;*
*Benemérita Universidad Autónoma de Puebla, **Mexico**;*
*Centro de Investigación y de Estudios Avanzados, **Mexico**;*
*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
*Universidad Autónoma de Sinaloa, **Mexico**;*
*Universidad de Colima, **Mexico**;*
*Universidad de Sonora, **Mexico**;*
*Universidad Michoacana de San Nicolás de Hidalgo, **Mexico***
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*

*Belgorod National Research University, **Russia**;*
*Institute for Nuclear Research of the RAS, Moscow, **Russia**;*
*High School of Economics University, Moscow, **Russia***
*National Research Nuclear University MEPhI , Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*National Research Center "Kurchatov Institute", **Russia**;*
*Peter the Great St. Petersburg Polytechnic University Saint Petersburg, **Russia**;*
*Plekhanov Russian University of Economics, Moscow, **Russia**;*
*St.Petersburg State University, **Russia**;*
*Skobeltsyn Institute of Nuclear Physics, Moscow, **Russia**;*
*Petersburg Nuclear Physics Institute, Gatchina**, Russia**;*
*Vinča Institute of Nuclear Sciences**, Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

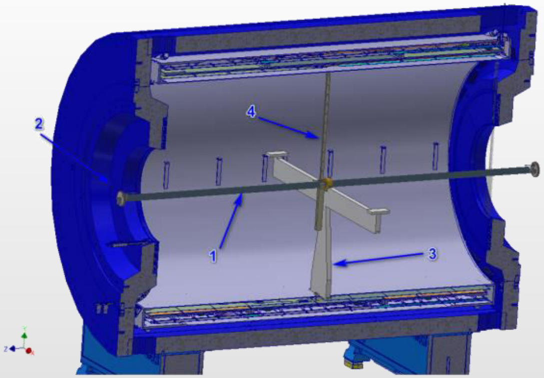
Activities in the MPD Hall

Cryogenic platform

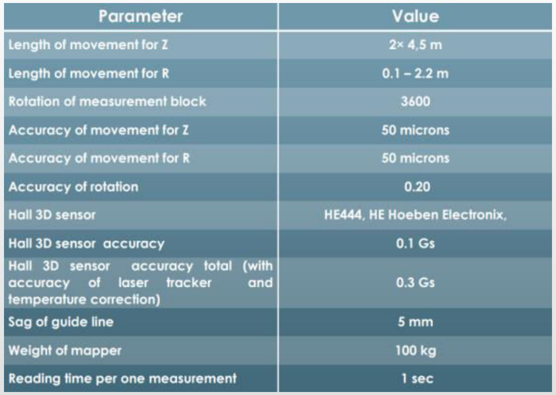
Chimney

Cryogenic pipes

Novosibirsk BINP magnetic field mapper



1. Aluminum (carbon fiber plastic) guiding rod
2. End cap fixation
3. Intermediate support
4. Carbon fiber plastic carriage



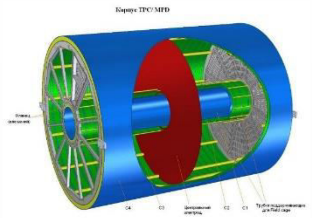
Parameter	Value
Length of movement for Z	2× 4,5 m
Length of movement for R	0.1 – 2.2 m
Rotation of measurement block	3600
Accuracy of movement for Z	50 microns
Accuracy of movement for R	50 microns
Accuracy of rotation	0.20
Hall 3D sensor	HE444, HE Hoeben Electronix,
Hall 3D sensor accuracy	0.1 Gs
Hall 3D sensor accuracy total (with accuracy of laser tracker and temperature correction)	0.3 Gs
Sag of guide line	5 mm
Weight of mapper	100 kg
Reading time per one measurement	1 sec

Carbon fiber support frame
sagita ~ 5 mm at full load

- ❖ Test cooling to 70^0 K in February-March
- ❖ Cooling to LHe → second half of 2024 → MF measurements → installation of carbon fiber support frame and subsystems

Barrel subsystems in production

TPC – central tracking detector

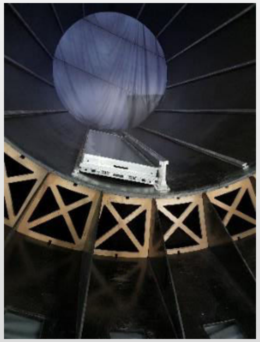


TPC cylinders, central membrane, service wheels, readout chambers,
gas system - ready - final vessel assembly by the end of year

TOF

TOF modules in storage (28 in total)

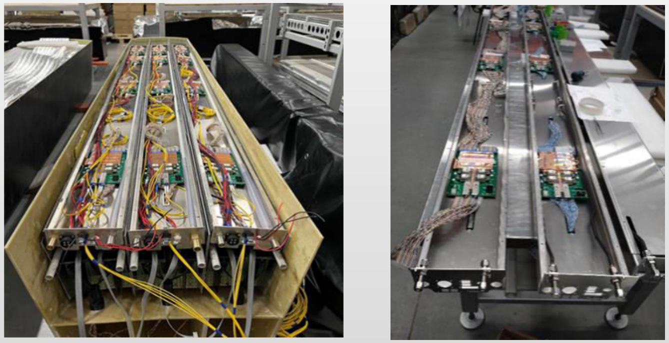
Module in the frame



Production of MRPC detectors was completed in September 2022, (107%)
All 28 TOF modules are assembled → long-term cosmic ray tests
Electronics & cables, HV distribution modules → in stock

ECAL

Half-sectors at different stages of assembly



Production rate ~ 10 half-sectors per month
Installation procedure for electronics in half-sectors is under development

MPD physics program

G. Feofilov, P. Parfenov

Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

D. Peresunko, Chi Yang

Electromagnetic probes

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

TPC response using GANs

- Использование генеративно-состязательных сетей (GAN) для быстрого моделирования сигналов в детекторе TPC → отклик на прохождение через детектор заряженных частиц

- Команда ВШЭ (Ф. Ратников, А. Маевский, и др.)

Eur. Phys. J. C (2021) 81:599
https://doi.org/10.1140/epjc/s10052-021-09366-4

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Simulating the time projection chamber responses at the MPD detector using generative adversarial networks

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Received: 13 December 2020 / Accepted: 23 June 2021 / Published online: 10 July 2021
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Abstract High energy physics experiments rely heavily on the detailed detector simulation models in many tasks. Running these detailed models typically requires a notable amount of the computing time available to the experiments. In this work, we demonstrate a new approach to speed up the simulation of the Time Projection Chamber tracker of the MPD experiment at the NICA accelerator complex. Our method is based on a Generative Adversarial Network – a deep learning technique allowing for implicit estimation of the population distribution for a given set of objects. This approach lets us learn and then sample from the distribution of raw detector responses, conditioned on the parameters of the charged particle tracks. To evaluate the quality of the proposed model, we integrate a prototype into the MPD software stack and demonstrate that it produces high-quality events similar to the detailed simulator, with a speed-up of at least an order of magnitude. The prototype is trained on the responses from the inner part of the detector and, once expanded to the full detector, should be ready for use in physics tasks.

1 Introduction

Computer simulations of high-energy physics experiments play a crucial role in a variety of relevant tasks, including detector geometry optimization [1,2], selecting best analysis strategies [3,4], and testing the Standard Model (SM) predictions and searching for new phenomena beyond the SM [5,6]. For a typical experimental data analysis, the number of simulated events usually translates directly to the uncertainty of the final physics result. The amount of computational resources spent on the simulations usually takes a notable fraction of the total computing capabilities of an experiment and is comparable with that spent on the real data processing [7,8]. Therefore, faster approaches to event generation and simulation are in great demand for the existing and future high energy physics experiments.

The MPD detector is one of the two experiments at the NICA accelerator complex – a new heavy ion accelerator facility being constructed at the Joint Institute for Nuclear Research and located in Dubna, Russia [9,10]. The complex is designed to study the properties of dense baryonic matter. For the tracking, MPD utilizes a time projection chamber (TPC) in the central barrel [11]. TPC simulation is very CPU-intensive [12], and hence a fast simulation approach for TPC is highly desirable.

A typical approach to constructing models for fast simulation of particle physics detectors is to use a simplified detector geometry and a simplified model of the interaction of particles with matter [13]. This approach is justified for subsystems with a flat sensitive volume, such as silicon trackers, that measure the two-dimensional coordinate of a passing particle. For systems with a large volume, such as calorimeters or TPC-based trackers, this approach makes it difficult to achieve a reasonable compromise between accuracy and simulation speed.

Another fast simulation approach is an analytical parameterization of the detector responses, as can be seen in shower shape parameterizations for calorimeters [14]. This approach can significantly speed up the calorimeter simulation, but it makes it difficult to achieve high quality simulated data. A common solution for calorimeters is also to use the so-called "frozen showers" [13] when detailed simulated system responses are stored as a response library for subsequent reuse.

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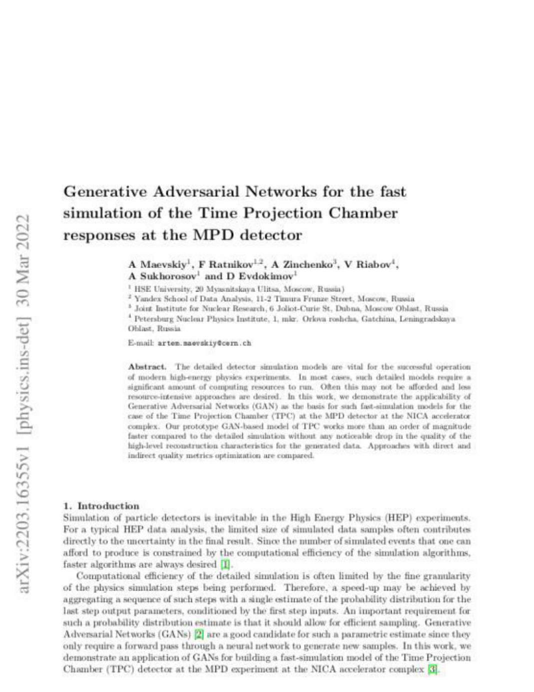
[b] e-mail: fedor.ratnikov@cern.ch
[c] e-mail: alexander.zinchenko@jinr.ru
[d] e-mail: riabovvg@gmail.com

Springer



arXiv:2203.16355v1 [physics.ins-det] 30 Mar 2022

Generative Adversarial Networks for the fast simulation of the Time Projection Chamber responses at the MPD detector

A Maevskiy[1], F Ratnikov[1,2], A Zinchenko[3], V Riabov[4], A Sukhorosov[1] and D Evdokimov[1]
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[2] Yandex School of Data Analysis, 11-2 Timura Frunze Street, Moscow, Russia
[3] Joint Institute for Nuclear Research, 6 Joliot-Curie St, Dubna, Moscow Oblast, Russia
[4] Petersburg Nuclear Physics Institute, 1, mkr. Orlova roshcha, Gatchina, Leningradskaya Oblast, Russia

E-mail: `artem.maevskiy@cern.ch`

Abstract. The detailed detector simulation models are vital for the successful operation of modern high-energy physics experiments. In most cases, such detailed models require a significant amount of computing resources to run. Often this may not be afforded and less resource-intensive approaches are desired. In this work, we demonstrate the applicability of Generative Adversarial Networks (GAN) as the basis for such fast-simulation models for the case of the Time Projection Chamber (TPC) at the MPD detector at the NICA accelerator complex. Our prototype GAN-based model of TPC works more than an order of magnitude faster compared to the detailed simulation without any noticeable drop in the quality of the high-level reconstruction characteristics for the generated data. Approaches with direct and indirect quality metrics optimization are compared.

1. Introduction

Simulation of particle detectors is inevitable in the High Energy Physics (HEP) experiments. For a typical HEP data analysis, the limited size of simulated data samples often contributes directly to the uncertainty in the final result. Since the number of simulated events that one can afford to produce is constrained by the computational efficiency of the simulation algorithms, faster algorithms are always desired [1].

Computational efficiency of the detailed simulation is often limited by the fine granularity of the physics simulation steps being performed. Therefore, a speed-up may be achieved by aggregating a sequence of such steps with a single estimate of the probability distribution for the last step output parameters, conditioned by the first step inputs. An important requirement for such a probability distribution estimate is that it should allow for efficient sampling. Generative Adversarial Networks (GANs) [2] are a good candidate for such a parametric estimate since they only require a forward pass through a neural network to generate new samples. In this work, we demonstrate an application of GANs for building a fast-simulation model of the Time Projection Chamber (TPC) detector at the MPD experiment at the NICA accelerator complex [3].

arXiv:2207.04340v1 [hep-ex] 9 Jul 2022

Generative Surrogates for Fast Simulation: TPC Case

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Abstract

Simulation of High Energy Physics experiments is widely used, necessary for both detector and physics studies. Detailed Monte-Carlo simulation algorithms are often limited due to the computational complexity of such methods, and therefore faster approaches are desired. Generative Adversarial Networks (GANs) are well suited for aggregating a number of detailed simulation steps into a surrogate probability density estimator readily available for fast sampling. In this work, we demonstrate the power of the GAN-based fast simulation model on the use case of simulating the response for the Time Projection Chamber (TPC) in the MPD experiment at the NICA accelerator complex. We show that our model can generate high-fidelity TPC responses, while accelerating the TPC simulation by at least an order of magnitude. We describe alternative representation approaches for this problem and also outline the roadmap for the deployment of our method into the software stack of the experiment.

Keywords: fast simulation, time projection chamber, generative adversarial network

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Preprint submitted to Nuclear Instruments and Methods in Physics Research A July 12, 2022

TPC response using GANs - performance

- Моделирование сигналов на считываемых падах:

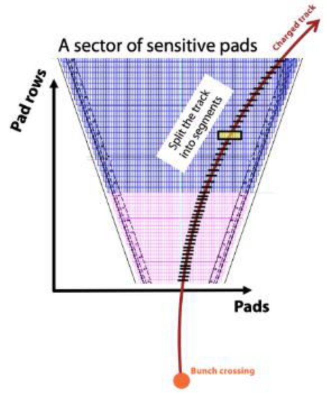


Figure 1. The transverse projection of a track on top of a sector of sensitive pads of the detector. The track is split into segments contributing to each of the rows of sensitive pads.

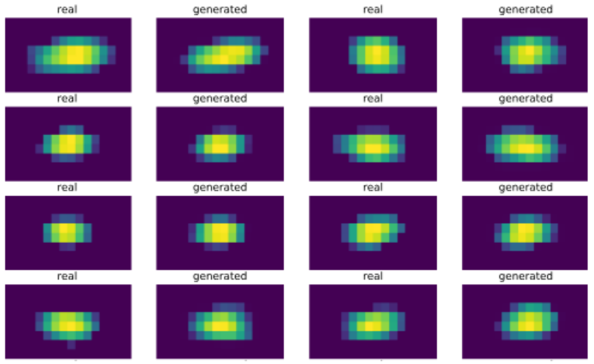
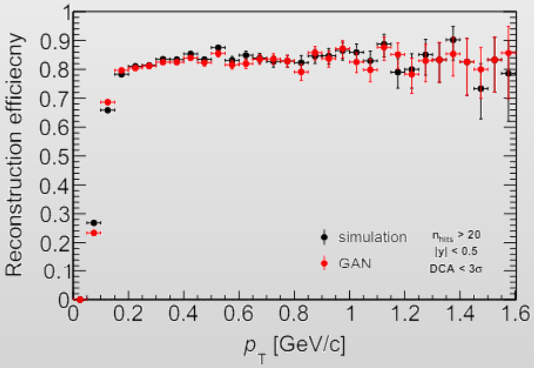
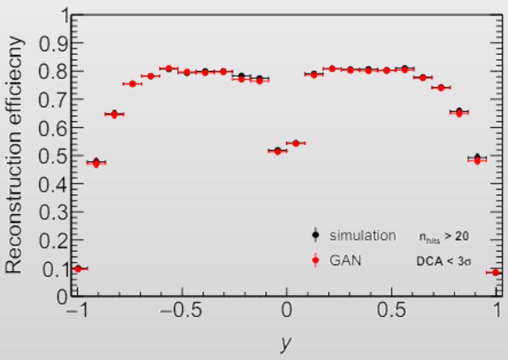
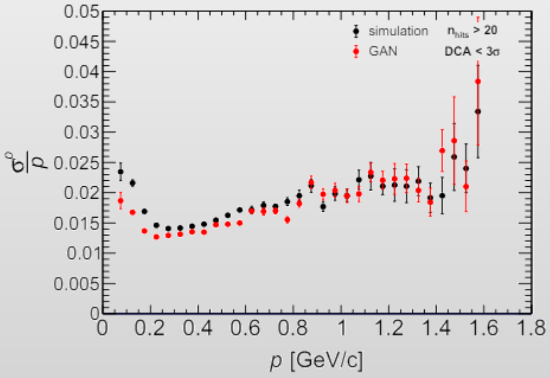


Fig. 1. Examples of the generated pad responses. Vertical and horizontal axes correspond to the pad and time bins, respectively. Each image from the validation dataset (1st and 3rd columns) is paired up with a generated image (2nd and 4th columns) obtained for the same values of the conditional variables.

- GAN-смоделированные сигналы → сравнимые характеристики детектора (разрешение, эффективность и т.д.) :







Актуальные задачи и требуемые специалисты

- Создание, запуск и эксплуатация экспериментальной установки:
  - ✓ Электрики, монтажники, конструкторы, специалисты по криогенике …
  - ✓ Системы контроля и мониторинга состояния детекторов, магнитов, газовой системы (aka DCS) (LV, HV, T, утечки, состав газовой смеси …)
  - ✓ Система аварийной индикации и реагирования на внештатные ситуации

- Разработчики программного обеспечения:
  - ✓ Система онлайн контроля качества поступающих данных (QA)
  - ✓ Онлайн и офлайн калибровка детекторных подсистем
  - ✓ Реконструкция сигналов в детекторных подсистемах, глобальные трекинг и ассоциация сигналов (включая моделирование откликов TPC и ECAL с использованием генеративных моделей)

- Обработка экспериментальных данных:
  - ✓ Физический анализ данных и интерпретация результатов → использование классических методов обработки экспериментальных данных будет наиболее уместным и приоритетным в первые годы работы экспериментальной установки
  - ✓ Внедрение продвинутых методов анализа данных, включая элементы машинного обучения (мультивариативные анализы для идентификации адронов, измерения гиперонов, нейтральных мезонов, диэлектронного континуума, D-мезонов и т.д.) → экзотика на начальном этапе, но смогут получить признание в случае демонстрации успеха

Possible application areas of machine learning techniques at MPD/NICA, Contribution to GRID 2018, 615-619
Dielectron analysis: Machine learning study, https://indico.jinr.ru/event/4506/
Gradient Boosted Decision Tree for Particle Identification at MPD, https://indico.jinr.ru/event/4314/
Photon and neutral meson reconstruction, https://indico.jinr.ru/event/4080/

BACKUP