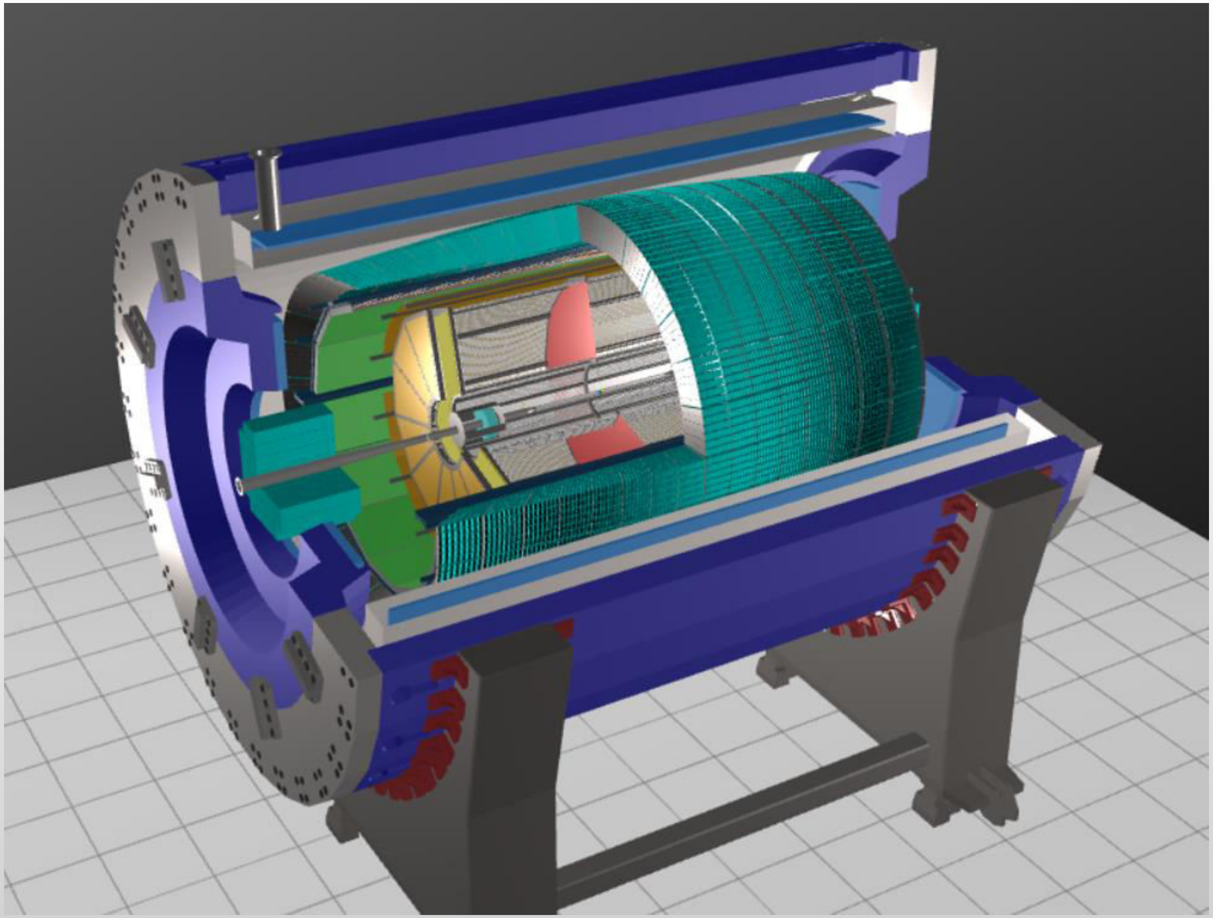
Nuclotron based Ion Colider fAcility

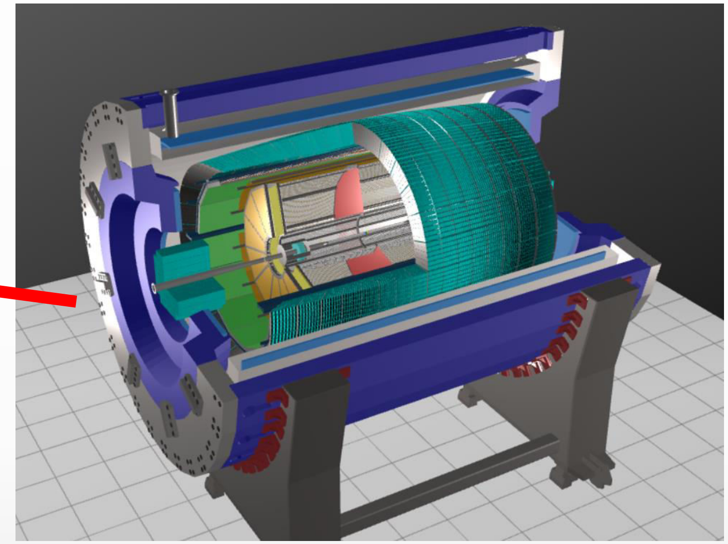
Статус эксперимента MPD-NICA

В. Рябов, ЛРЯФ ОФВЭ



MPD @ NICA

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



Length	340 cm
Vessel outer radius	140 cm
Vessel inner radius	27 cm
Default magnetic field	0.5 T
Drift gas mixture	90% Ar+10% CH_4
Maximum event rate	7 kHz ($L = 10^{27}$ $cm^{-2}s^{-1}$)

- Expected beam condition for the first year(s) :
  - ✓ not-optimal beam optics → wide z-vertex, σ_z ~ 50 cm
  - ✓ reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
  - ✓ first beams: Bi+Bi / Xe+Xe at $\sqrt{s_{NN}} \leq 7$ GeV

TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$

TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$

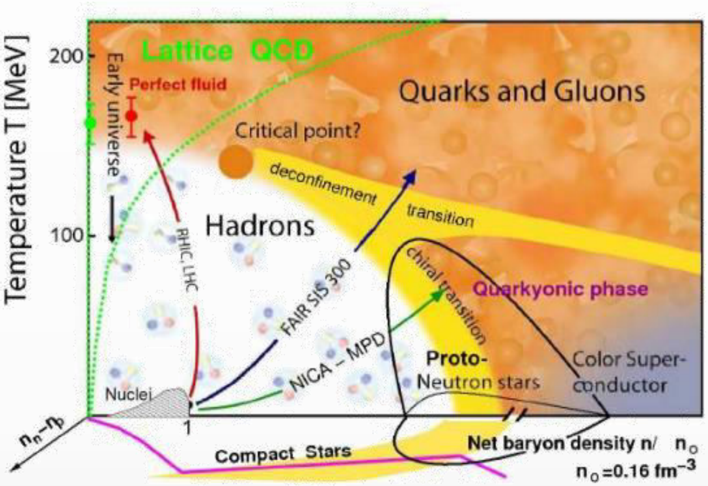
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$

FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

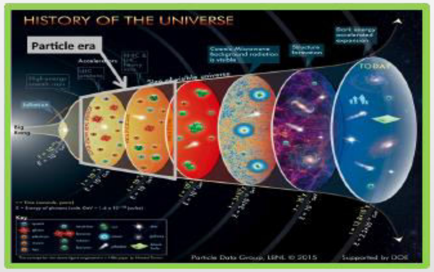
Commissioning and first data taking ~ 2025

Heavy-ion collisions

- ❖ Study QCD under extreme conditions of temperature and density
- ❖ Explore the QCD phase diagram, search for the QGP and study its properties

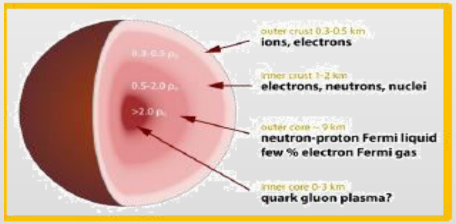


- ✓ primordial form of QCD matter at high temperatures and/or (net)baryon densities
- ✓ present during the first microseconds after Big Bang and in cores of the compact neutron stars / mergers
- ✓ provide important insights on the origin of mass for matter, and how quarks are confined into hadrons



High temperature:
Early Universe evolution

High baryon density:
Inner structure of
compact stars

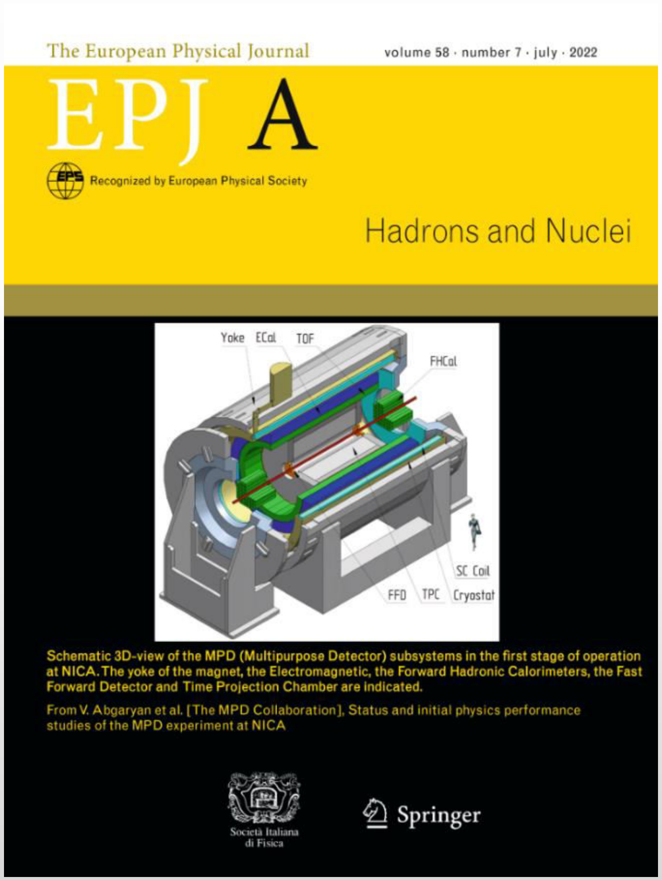


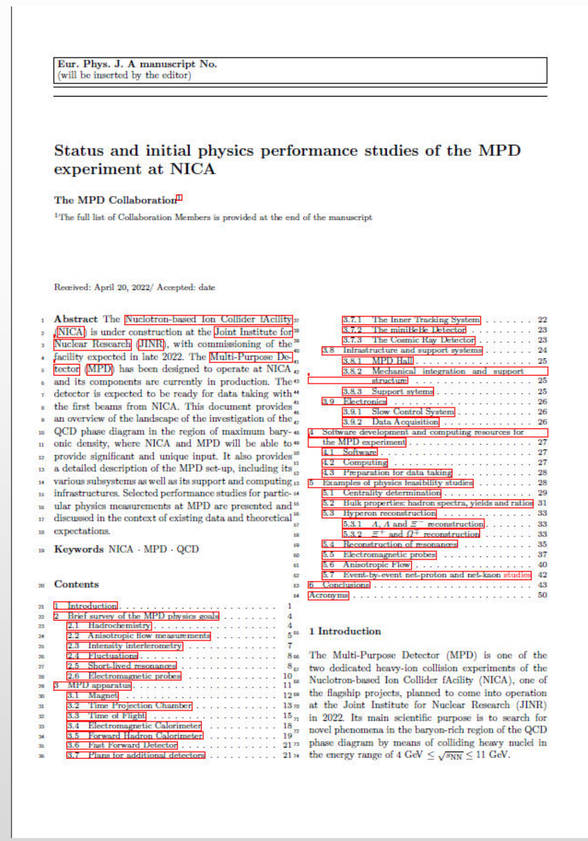
- ❖ At NICA, both BM@N and MPD study QCD medium at extreme net baryon densities

Status and performance

- MPD publications: over 200 in total for hardware, software and physics studies (SPIRES)
- First collaboration paper recently published EPJA (~ 50 pages): Eur.Phys.J.A 58 (2022) 7, 140

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





Eur. Phys. J. A manuscript No.
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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

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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

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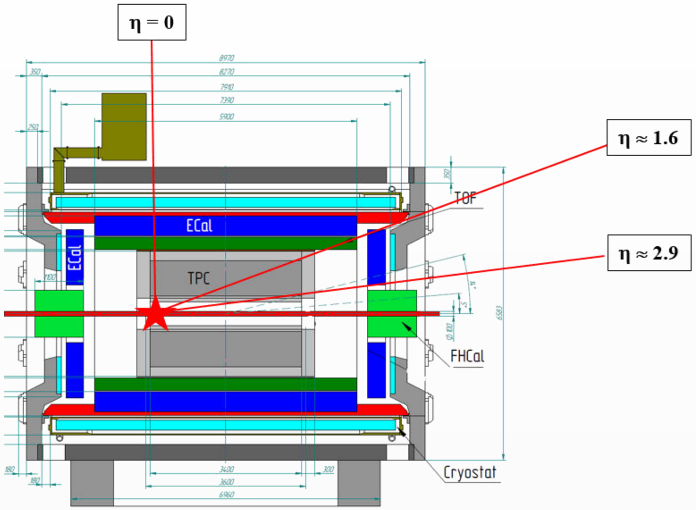
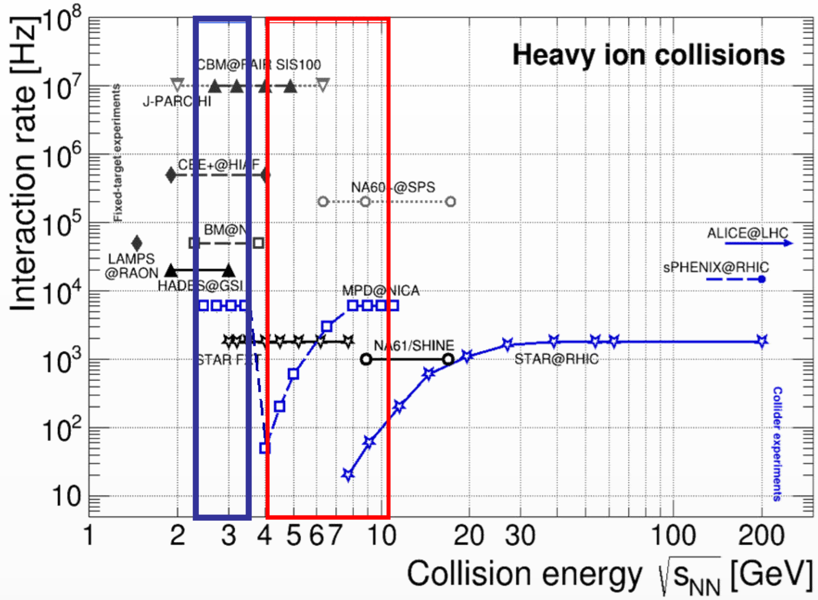
1 Introduction

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 $\le \sqrt{s_{NN}} \le$ 11 GeV.

NICA operation modes

- With a wire-target at z ~ -100 cm





❖ Discussing the option of NICA operation in the collider and fixed-target modes in the same campaign

❖ Fixed-target mode: one beam + thin wire (~ 100 μm) close to the edge of the MPD central barrel:

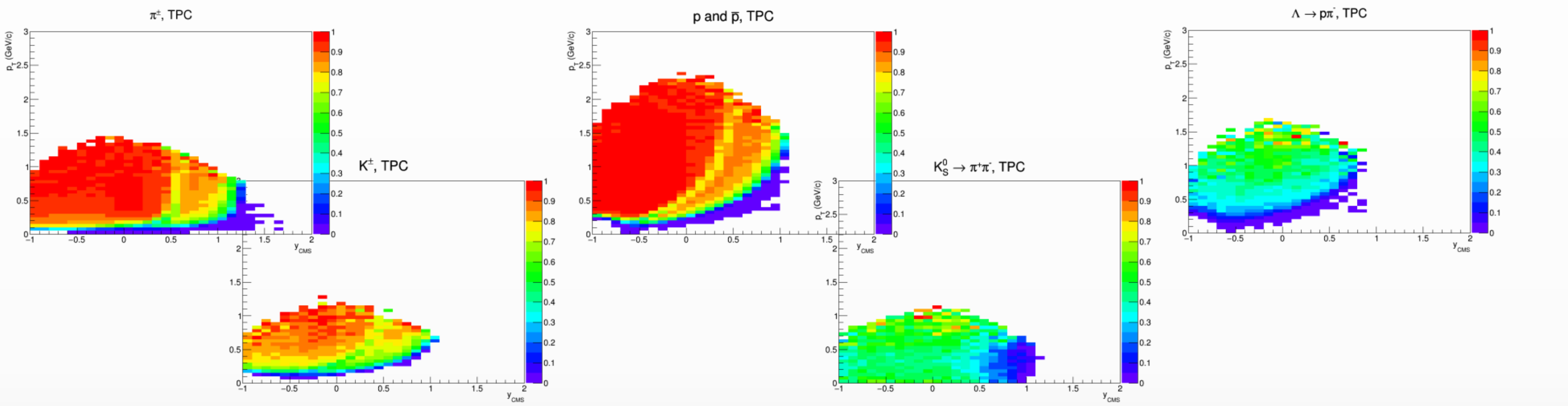
- ✓ extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N and CBM)
- ✓ solves problem of low event rate at lower collision energies (only ~ 50 Hz at $\sqrt{s_{NN}}$ = 4 GeV at design luminosity)
- ✓ backup start-up solution (too low luminosity, only one beam, etc.)

Unique capability of target and collision energy overlap between the experiments

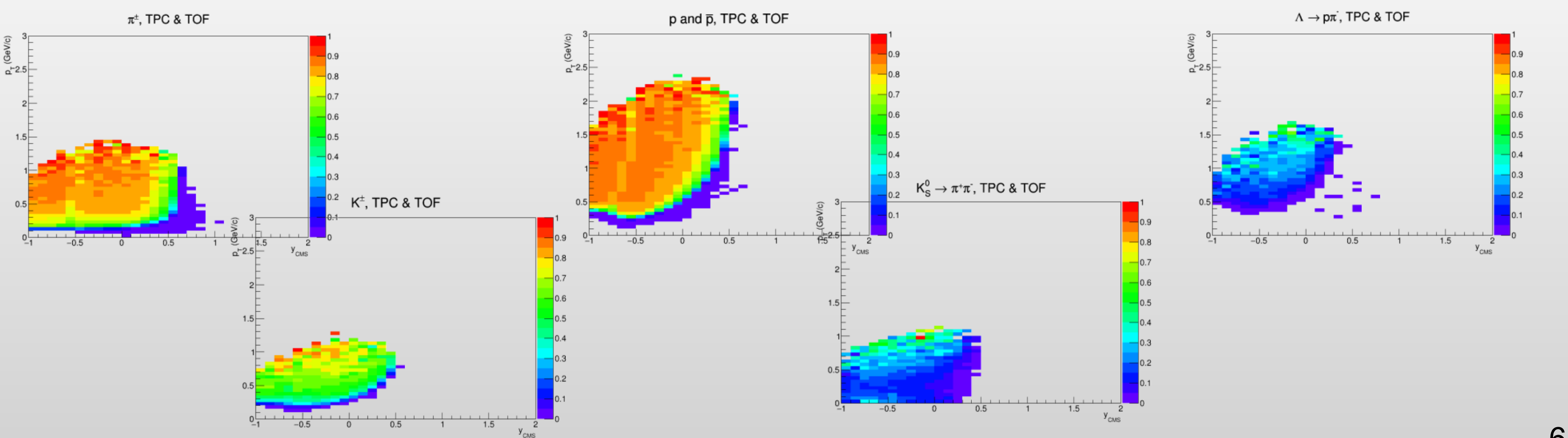
Efficiency for π/K/p/Ks/Λ, z_{vertex} = - 85 cm

Basic track selections: $N_{hits} > 10$; DCA < 2 cm; Primary particles ($R_{production} < 1$ cm)

- TPC-only tracks:



- TPC + TOF tracks:



MPD strategy

❖ MPD strategy – high-luminosity scans in **energy** and **system size** to measure a wide variety of signals:

- ✓ order of the phase transition and search for the QCD critical point → structure of the QCD phase diagram
- ✓ hypernuclei and equation of state at high baryon densities → inner structure of compact stars, star mergers

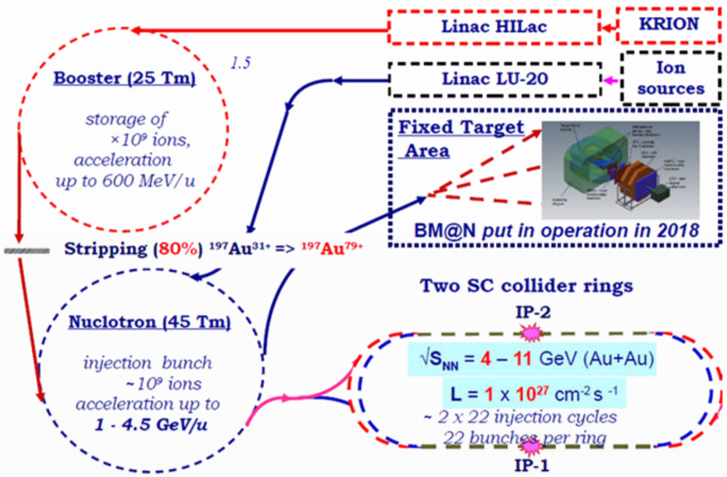
❖ Scans to be carried out using the **same apparatus** with all the advantages of collider experiments:

- ✓ maximum phase space, minimally biased acceptance, free of target parasitic effects
- ✓ correlated systematic effects for different systems and energies → simplified extraction of physical signals

❖ Continuously develop physical program based on the recent advancements in the field:

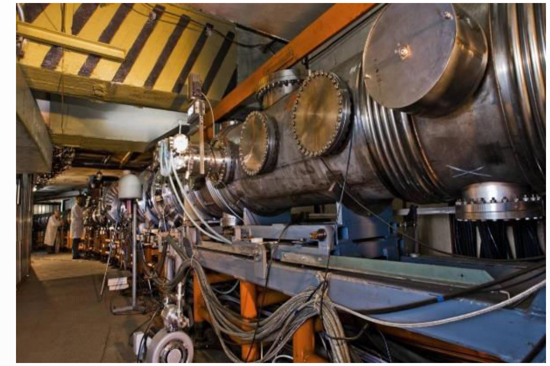
- ✓ identified particle spectra and ratios, collective flow and femtoscopy, production of strangeness and hypernuclei net-proton fluctuations, global polarization of hyperond and spin alignment of vector mesons, dilepton continuum and LVMs, etc.

Milestones for accelerator complex



Booster

Nuclotron

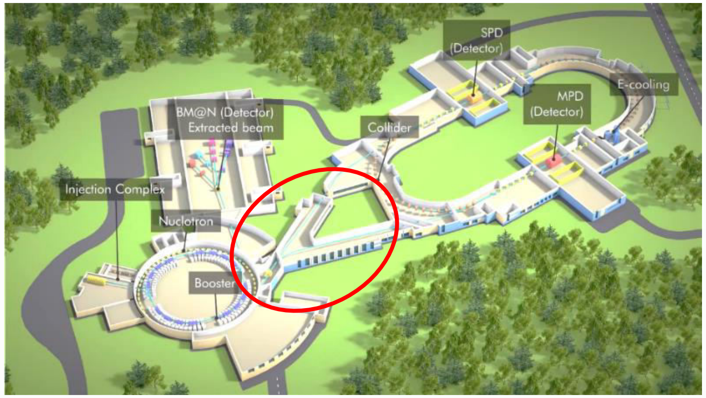


❖ Stages of the accelerator complex commissioning

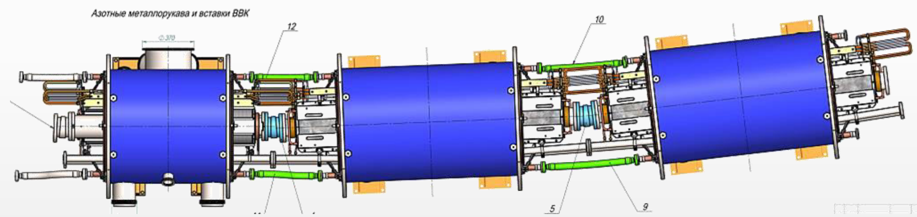
- ✓ HILAC + transfer line to Booster → commissioned in 2018 with He^{1+}, Fe^{14+}, C^{4+}, Ar^{14+} and Xe^{28+}
- ✓ HILAC + Booster → first run in November-December, 2020 with He^{1+}
- ✓ HILAC + Booster + transfer line to Nuclotron → second run in October, 2021 with He^{1+} and Fe^{16+}
- ✓ HILAC + Booster + Nuclotron + transfer line to BM@N → third run in Jan. – Apr., 2022 with C^{6+}
- ✓ HILAC + Booster + Nuclotron + transfer line to BM@N -> fourth run in September, 2022 – February, 2023 with Ar and Xe beams → 550+ M events at BM@N

Collider

Nuclotron-NICA transfer line



NICA collider



Quadrupole Dipole Dipole

- ❖ Magnet and RF installation: by the middle of 2024
- ❖ First technological and cryogenic run of collider: end of 2024 - beginning of 2025
- ❖ Fast extraction system from the Nuclotron: June of 2024
- ❖ Nuclotron-collider transfer line: Autumn of 2024
- ❖ First run with beams: 2025

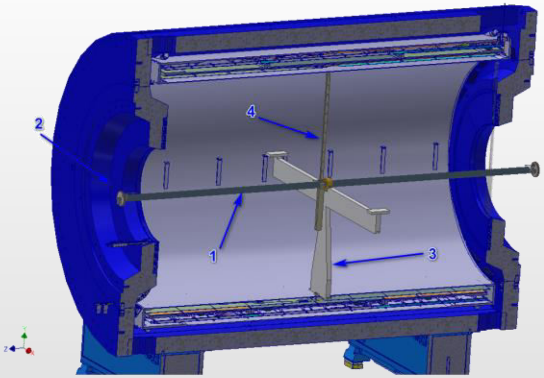
Activities in the MPD Hall

Top platform (cryogenics, power supplies, control system)

Chimney

Cryogenic platform

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

- Yoke, TRIM coils, top platform, chimney assembled, ongoing tests of the refrigerators and control Dewar
- Cooling to LN2 and LHe temperatures in the beginning of 2024 → MF measurements → central support frame

Electromagnetic calorimeter (ECAL)

- Sampling calorimeter with projective geometry (~70 tons):
  - ✓ 25 sectors (50 half-sectors); 2400 modules; 38,400 “shashlyk”-type Pb-Sc towers with segmentation of 4x4 cm^2
- 1600 modules (66%) have been produced (800 in Russia + 800 in China)
- Production of additional 400 modules in Russia is ongoing, use Russian-made WLS fibers → 83% in total
- Mass production of half-sectors in JINR by international team, 18 half-sectors assembled

Half-sectors at different stages of assembly

ECAL installation in the MPD: August, 2024

Time-of-Flight (TOF)

- ❖ The production of MRPC detectors was completed in September 2022, (107%) chambers
- ❖ TOF modules are assembled → long-term cosmic ray tests
- ❖ Electronics & cables, HV distribution modules, installation equipment - in stock

Storage of tested TOF modules

TOF installation bench in LHEP

- ❖ The equipment for installing the modules in the MPD is ready for use and stored in the laboratory

TOF installation in the MPD: September, 2024

Time Projection Chamber (TPC)

- TPC cylinders, central membrane and service wheels are ready, final vessel assembly by the end of 2023
- Read-out chambers (ROCs) - 24 tested chambers in stock + 4 tested spare chambers

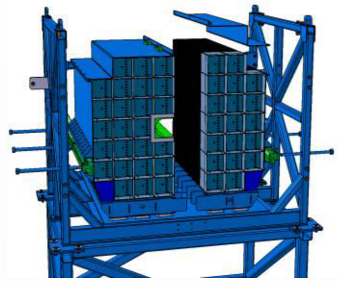
- Gas system ready – testing
- TPC FE electronics status:
  - ✓ 65% manufactured (967 pc)
  - ✓ no more problems with components → 100% available

- On critical path:
  - ✓ TPC rails prod./inst. – October-November, 2023
  - ✓ TPC cooling system – (INP BSU, Belarus): FEE cooling ready by Spring, 2024; thermostabilization panels by September, 2024;

TPC installation in the MPD: end of 2024

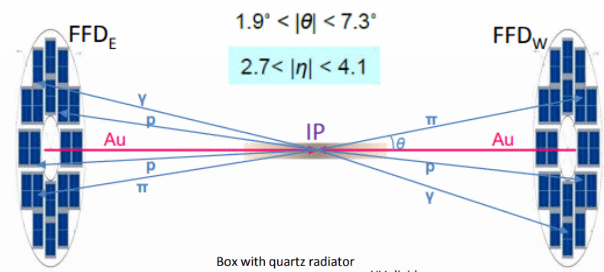
Forward subsystems in production

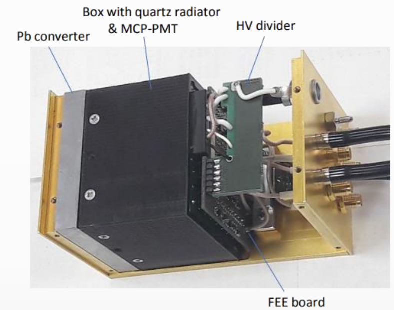
FHCAL



FHCAL modules have been produced and tested → installation in 2024

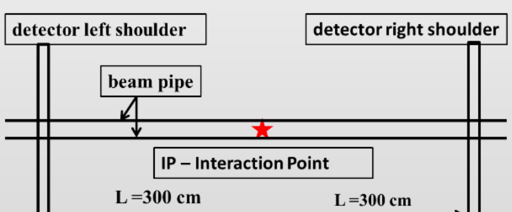
FFD





Cherenkov modules of FFDE and FFDW are available, mechanics of FFD sub-detectors is available for installation in container with vacuum beam tube

Beam and luminosity monitoring



Measurement of transverse sizes of the bunches
Transvers and longitudinal convergence of bunches
Vertices distribution along the beam

- Two sets by 32 scintillator counters readout by SIMPs from both sides
- Observables & methods:
  - ✓ counting rate and z-vertex distribution ($\sigma_{z\text{-vertex}}$ ~ 5 cm with $\delta\tau$ ~ 300 ps)
  - ✓ Van der Meer and ΔZ scans for optimization of beam optics
- Beam tests of prototypes
- Mass production of scintillator detectors

MPD physics program

G. Feofilov, A. Aparin

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

MPD mass productions

- Physics feasibility studies using centralized large-scale MC productions → consistent picture of the MPD physical capabilities with the first data sets, preparation for real data analyses

- https://mpdforum.jinr.ru/c/mcprod/26:

  Request 25: General-purpose, 50M UrQMD BiBi@9.2 → **DONE**

  Request 26: General-purpose (trigger), 1M DCM-QGSM-SMM BiBi@9.2 → **DONE**

  Request 27: General-purpose (trigger), 1M PHQMD BiBi@9.2 → **DONE**

  Request 28: General-purpose with reduced magnetic field, 10M UrQMD BiBi@9.2 → **DONE**

  Request 29: General-purpose (hypernuclei), 20M PHQMD BiBi@9.2 → **DONE**

  Request 30: General-purpose (hyperon polarization), 15M PHSD BiBi@9.2 → **DONE**

  Request 31: General-purpose (femtoscopy), 50 M UrQMD BiBi@9.2 with freeze-out → **DONE**

  Request 32: General purpose (flow), 15M vHLLE+UrQMD with XPT → **DONE**

  Request 33: General purpose (FXT), (11 x 3)M UrQMD (mean field) → **DONE**

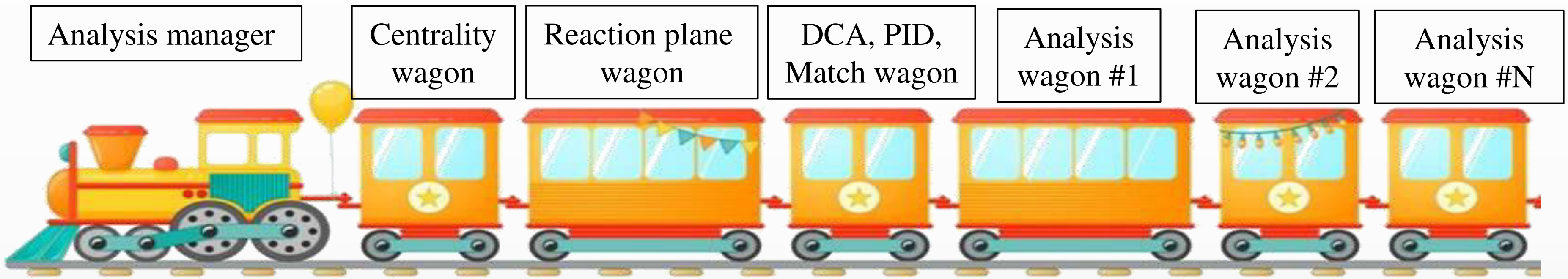
- Production comparable in size to the first expected real data samples test the existing computing and software infrastructure

- Develop realistic analysis methods and techniques, set priorities and find group leaders

Handling the big data sets

- Centralized Analysis Framework for access and analysis of data:
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes

- Analysis manager reads event into memory and calls wagons one-by-one to modify and/or analyze data:



- The Analysis manager and the first Wagons have been created, in MpdRoot @ mpdroot/physics
- Eventually all analysis codes will be committed to MpdRoot as Wagons
- The Train will run on a group of DST files, ~ 50k events → 1000 jobs for 50M production
- Results for all analyses/wagons run on a big production (~ 50 M events) in a day
- First runs of the Analysis Train started in August

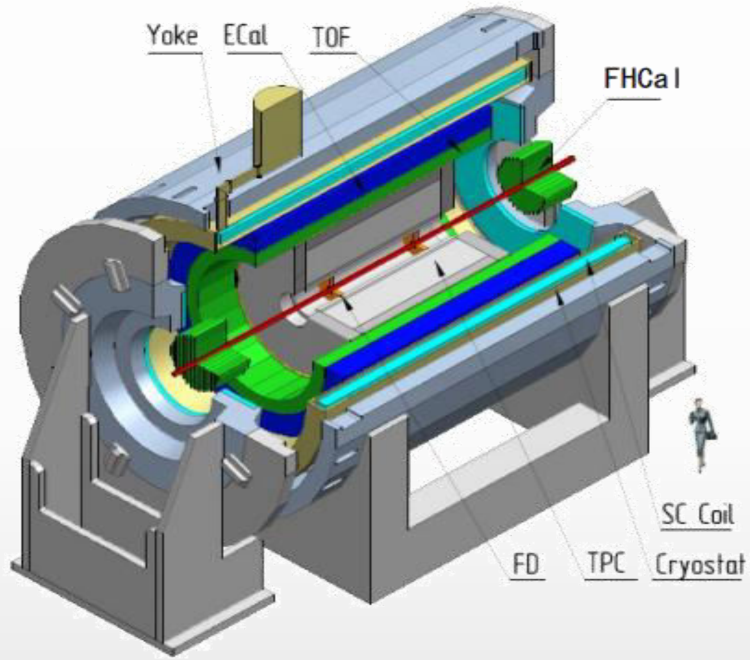
Multi-Purpose Detector (MPD) Collaboration

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***



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*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**;*
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*Tbilisi State University, Tbilisi, **Georgia**;*
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*Petersburg Nuclear Physics Institute, Gatchina**, Russia**;*
*Vinča Institute of Nuclear Sciences**, Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

Summary

- ❖ MPD construction and preparations for data taking are ongoing
- ❖ MPD commissioning and first data taking in 2025
- ❖ MPD has a solid physics program and can potentially provide unique results on the structure of the QCD phase diagram, provide insight into inner structure of compact start and neutron star mergers
- ❖ Develop realistic analysis techniques and tools using simulated data samples


Год Дракона
С Новым Годом!
yolbars77

BACKUP