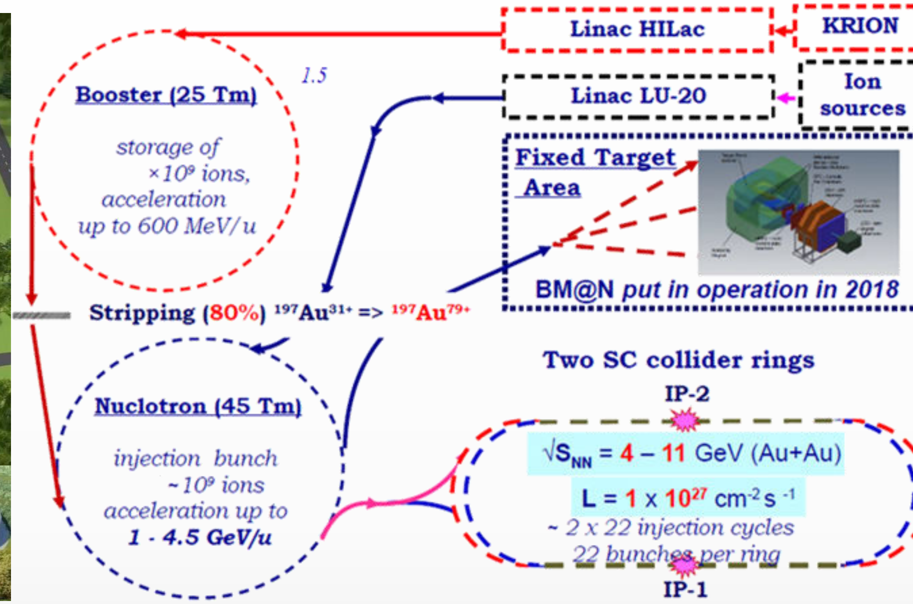
Nuclotron based Ion Colider fAcility

Статус эксперимента MPD-NICA

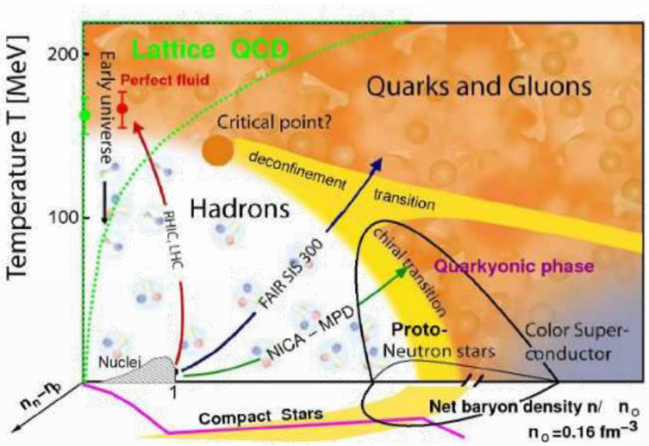
В. Рябов, ЛРЯФ ОФВЭ

NICA Project

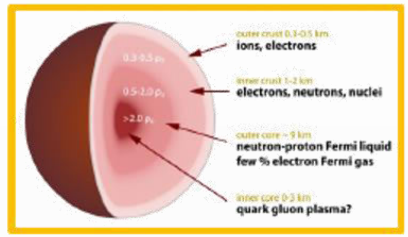


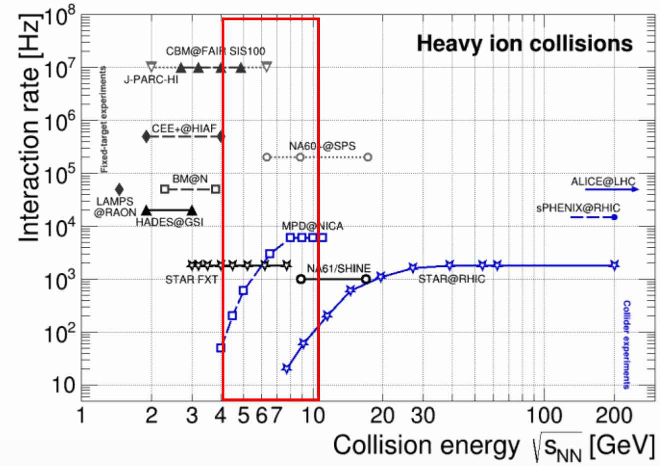
- Megascience project in Russia, which is approaching its full commissioning:
  - ✓ already running in the fixed-target mode – BM@N
  - ✓ start of operation in collider mode in 2023-2024 – MPD and later SPD
- Expected beam configuration in Stage-I:
  - ✓ not-optimal beam optics with wide z-vertex distribution, σ_z ~ 50 cm
  - ✓ reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
  - ✓ collision system available with the current sources: C (A=12), N (A=14), Ar (A=40), Fe (A=56), Kr (A=78-86), Xe (A=124-134), Bi (A=209) → start with Bi+Bi @ 9.2 GeV in 2023-2024

Relativistic heavy-ion collisions



high baryon densities
→ inner structure of
compact stars

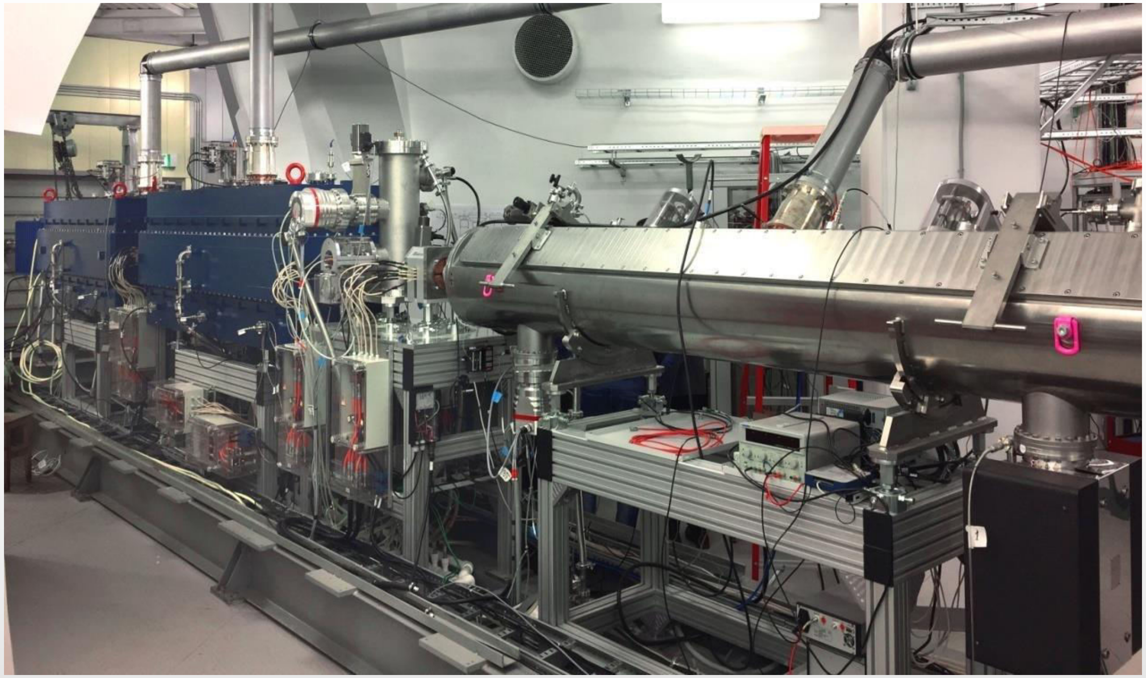




- ❖ At μ_B ~ 0, smooth crossover (lattice QCD calculations + data)
- ❖ At large μ_B, 1st order phase transition is expected → QCD critical point
- ❖ At NICA, both BM@N and MPD study QCD medium at extreme net baryon densities
- ❖ Many ongoing (HADES, NA61/Shine, STAR-BES) and future experiments in ~ same energy range
- ❖ MPD strategy – high-luminosity scans in energy and system size
  - ✓ 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 start, star mergers
- ❖ Scans to be carried out using the same apparatus with all the advantages of a collider experiment
  - ✓ maximum phase space, minimally biased acceptance, free of target parasitic effects
  - ✓ correlated systematic effects for different systems and energies → simplified extraction of physical signals

Milestones for accelerator complex

- 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+}

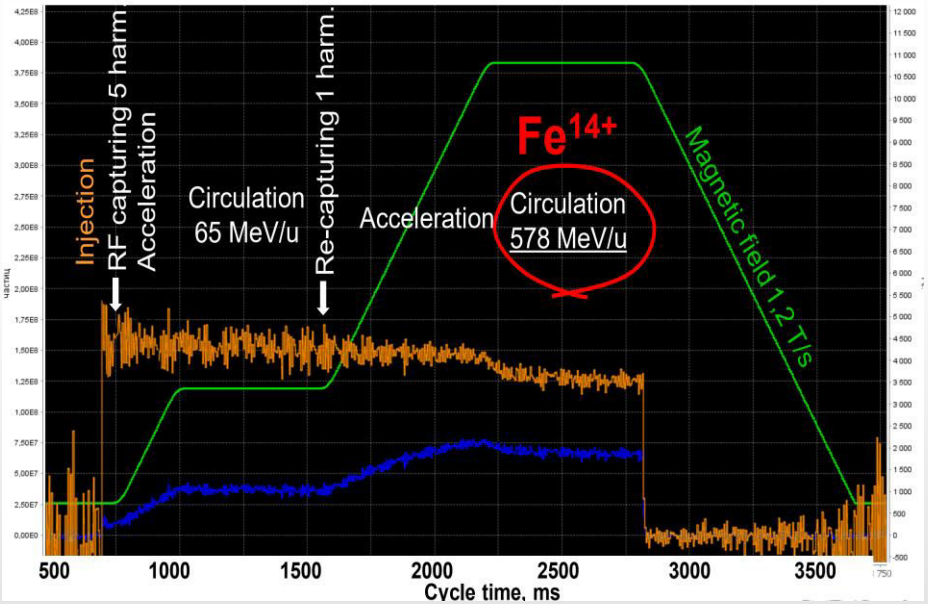


A/q (Target Ion Au^{31+})	**6.25**
Beam current	**< 10 emA**
Repetition rate	**< 10 Hz**
Output energy	**3.2 MeV/u**

Beam transition through the Booster injection beam line ~ 75%

Milestones for accelerator complex

- 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+}, energy up to 100 MeV/u
  - ✓ HILAC + Booster + transfer line to Nuclotron → second run in October, 2021 with He^{1+} and Fe^{16+}



He⁺ and Fe14⁺ ions, energy up to 578 MeV/u, residual gas pressure sufficiently low for heavy ions

Beam extraction from the Booster and transport line to the Nuclotron are put into operation and tuned

He⁺ and Fe14⁺ beams were transported through the beam transfer line to Nuclotron

Milestones for accelerator complex

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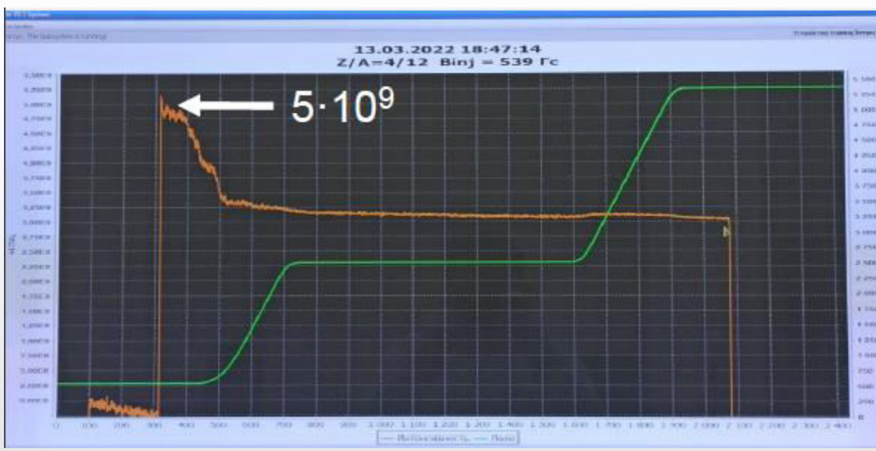
  - ✓ HILAC + Booster + Nuclotron + transfer line to BM@N → third run in Jan.-Apr., 2022 with C^{6+}

Booster



Nuclotron

Average efficiency ~ 30%, non-optimum stripping target thickness

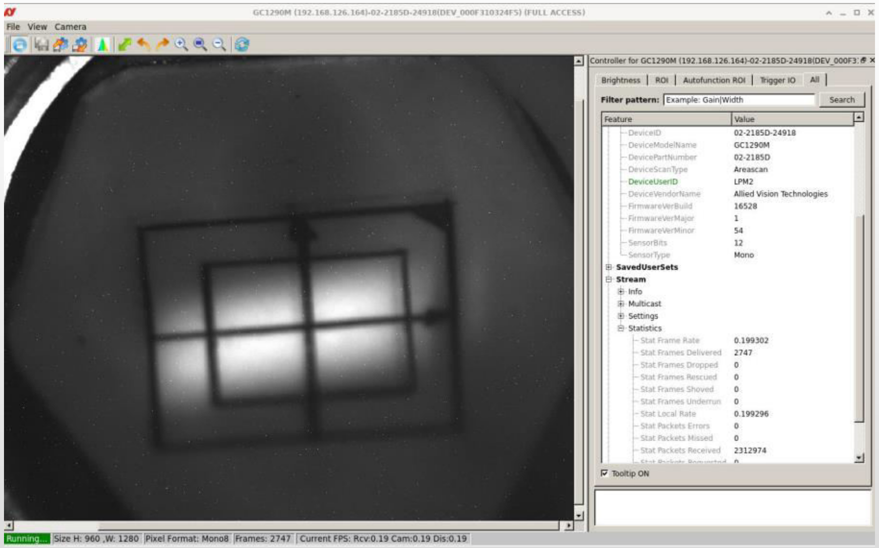
3 GeV/u Carbon beam transported to BM@N area : 5.03 – 29.03

2150 h of the facility operation, BM@N stable operation with beams for 24 days

SRC Collaboration collected 185 M events of carbon interactions with hydrogen target

Milestones for accelerator complex

- 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+}
  - ✓ ESIS + HILAC + Booster + modified Nuclotron + transfer line to BM@N -> fourth run started in September, 2022 with Ar and Xe beams → beams at BM@N to collect ~ $2{\cdot}10^9$ events



Beam of Xe on the phosphor screen at the end section of the Booster-Nuclotron transport line

Accelerator, next steps

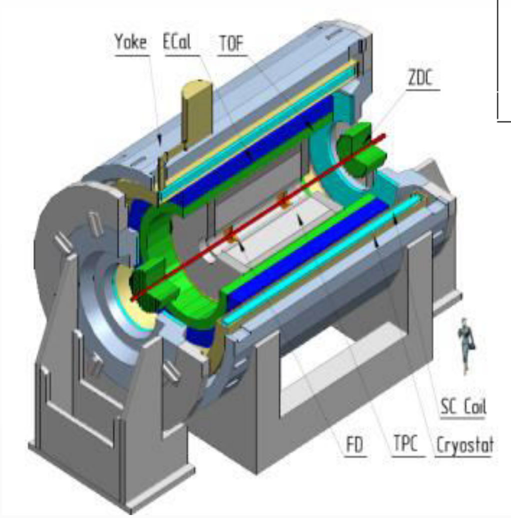
❖ All arc dipole magnets are installed in the tunnel

❖ Future plans:

- ✓ August-September, 2023 → technological run of NICA without beams
- ✓ End of 2023: first run with beams in the collider rings

Multi-Purpose Detector

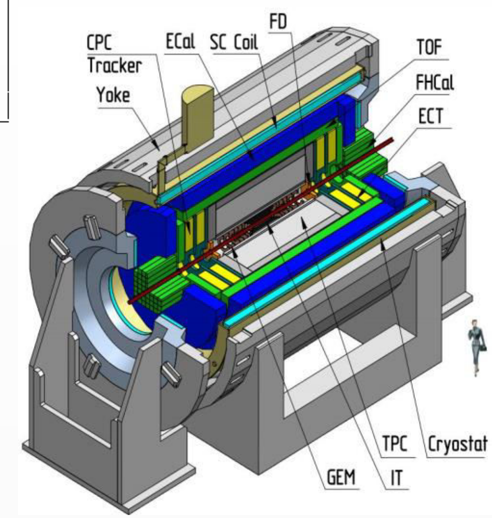
Stage- I



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 ($L = 10^{27}$ $cm^{-2}s^{-1}$)

upgrade

Stage- II



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

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

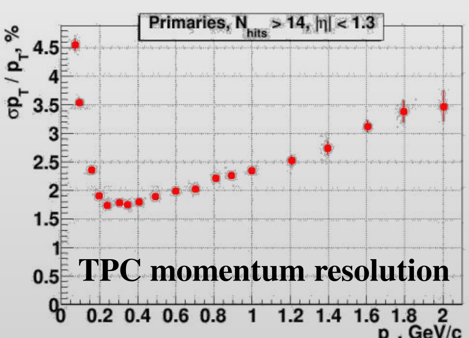
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$

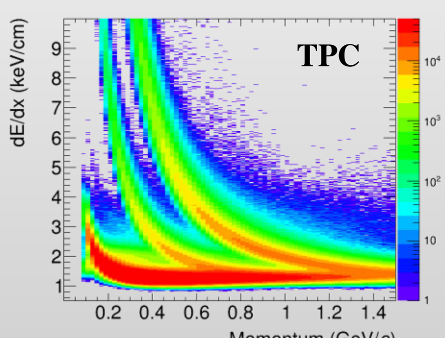
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

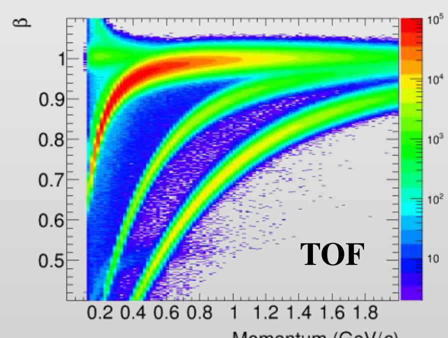
+ ITS (heavy-flavor measurements)

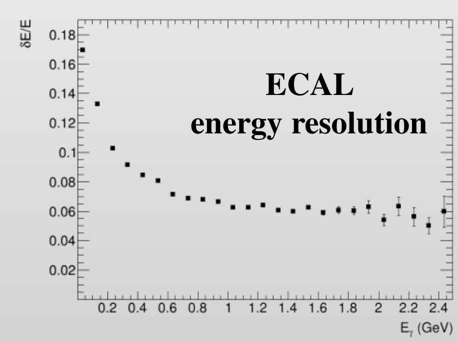
+ forward spectrometers

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



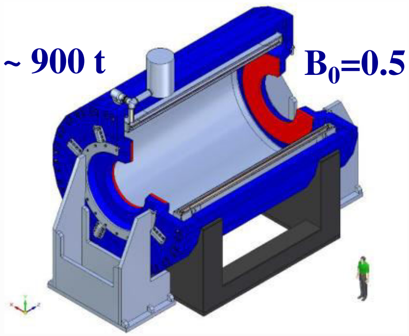






MPD subsystems in production

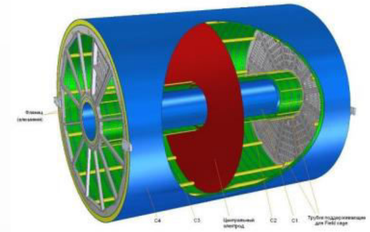
SC Solenoid + Iron Yoke



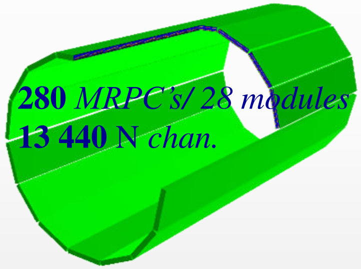
Goal is to cool down and power the magnet + magnetic field measurements in 2023

TPC – central tracking detector

ROCs done
Cyllinders done
Electronics in mass production



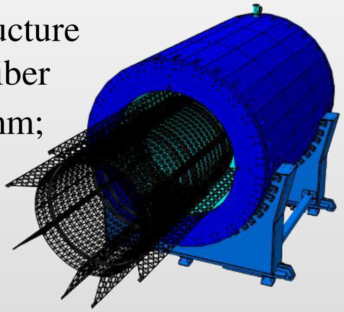
TOF



~ 100% of MRPCs (modules) are ready, cosmic tests ongoing

Support structure

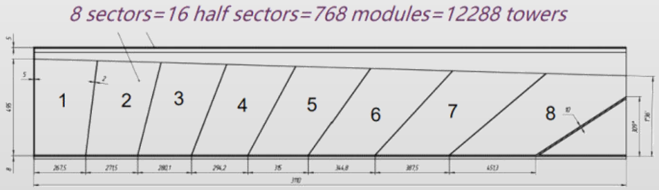
support structure of carbon fiber
sagite ~ **5** mm;
0,13 X_0

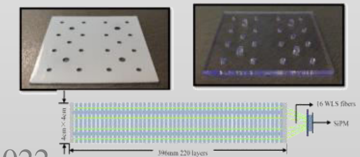


Constructed and delivered

ECAL (projective geometry)

38 400 towers
66-83% of the whole detector will be produced for Stage-I





Pb+Sc "shashlyk"-type towers

See http://mpd.jinr.ru/doc/mpd-tdr/ for details

MPD status and plans

- 2022:
  - ✓ preparation of the SC magnet for cooling
- 2023:
  - ✓ cooling the magnet and MF measurement
  - ✓ installation of the support frame and detectors
- 2024:
  - ✓ MPD commissioning
  - ✓ first run with BiBi@9.2 GeV, ~ 50-100 M events for alignment, calibration and physics
- 2025 and beyond:
  - ✓ Au+Au @ 11 GeV, design luminosity
  - ✓ system size and collision energy scans

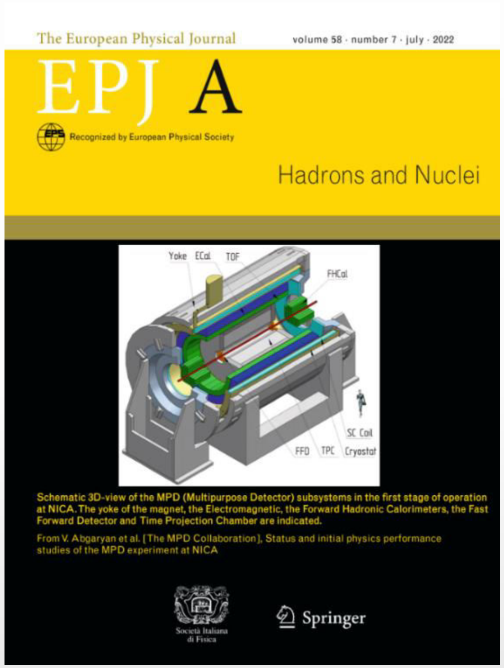
- Preparation of the MPD detector and experimental program is ongoing, all activities are continued
- All components of the MPD 1-st stage detector are in advanced state of production (subsystems, support frame, electronics platforms, LV/HV, control systems, cryogenics, cabling, etc.)

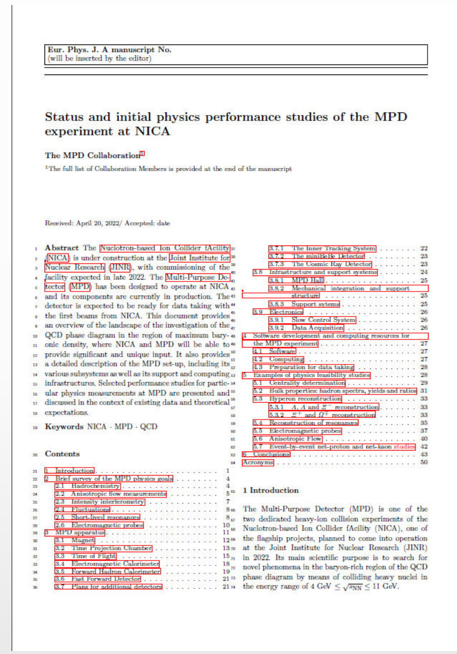
Schedule of the MPD-NICA is significantly affected by the current geopolitical situation (suspension of collaboration with CERN and Polish & Czech Republic member institutions, economical sanctions and problems with supplies of many components from western companies). The primary goal to have the MPD commissioned by the first beams at NICA collider is preserved.

Collaboration activity

- ❖ 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

<u>Status and initial physics performance studies of the MPD experiment at NICA</u>





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

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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

Contents

1 Introduction

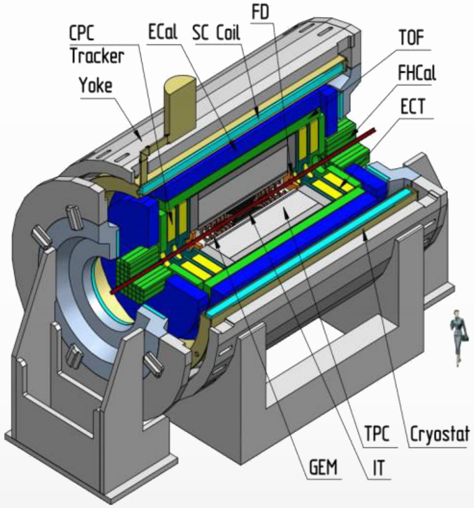
The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects, planned to come into operation at the Joint Institute for Nuclear Research (JINR) in 2022. Its main scientific purpose is to 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.

- ❖ MPD @ conferences: presented at all major conferences in the field:
  - ✓ Quark Matter (QM-2022), April 4-10
  - ✓ Nucleus-2022, July 11-16
  - ✓ ICHEP-2022, July 6-13
  - ✓ NST-2022, September 26-30
  - ✓ EuNPC-2022, October 24-28
  - ✓ DAE-BRNS CETHENP-2022, November 15-17
  - ✓ XVIII MWPF, November 21-25
  - ✓ ICPPA-2022, November, 29-December, 2

Possible contributions

1. Forward spectrometers for Phase-II MPD detector:

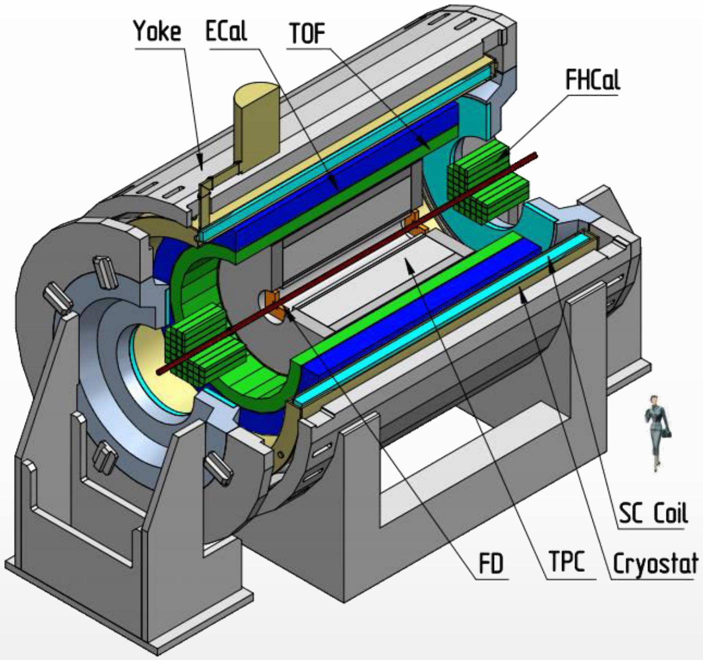
Stage- II



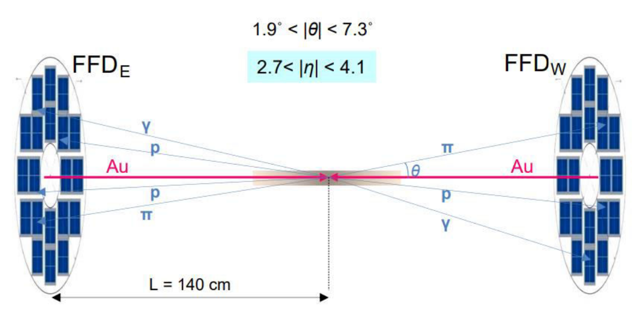
- ✓ Physics tasks for forward spectrometers, what observables should be studied at $|\eta| > 1\text{-}1.5$ (global hyperon polarization and vector meson spin alignment, angular distribution of fragments for the database, higher precision for integrated particle yields, ???)
- ✓ Understanding background situation in heavy-ion collisions
- ✓ Design of the forward spectrometer, see p.1
- ✓ Production of the detectors for the spectrometer

Possible contributions

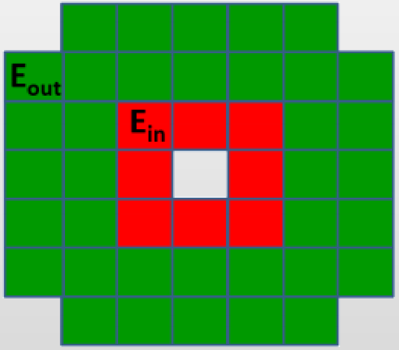
2. Trigger system for pp and light A-A collisions:



- FFD (Fast Forward Detector):
  - ✓ fast event triggering, T_0 for TOF and ECAL



- FHCAL (Forward Hadron Calorimeter):
  - ✓ fast event triggering, reaction plane detector



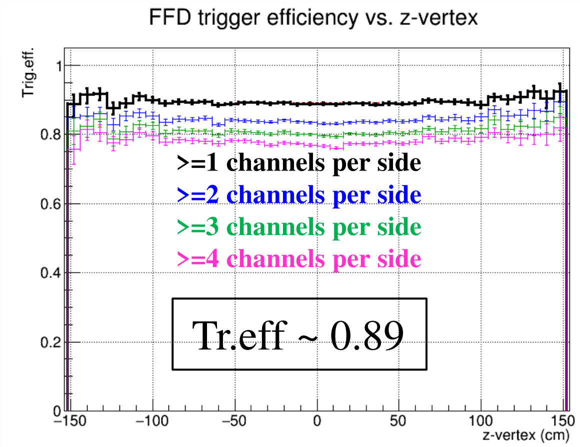
$2 < |\eta| < 5$

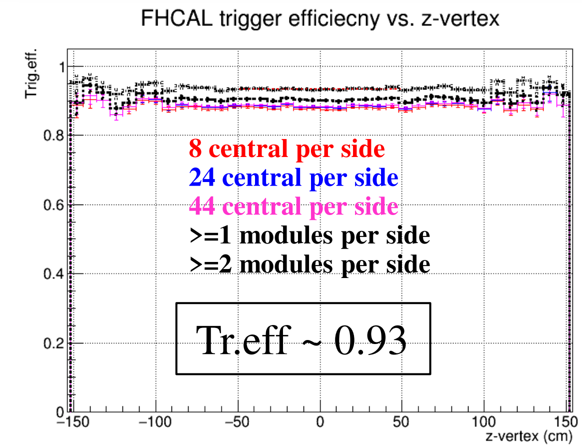
~ 1x1 m^2

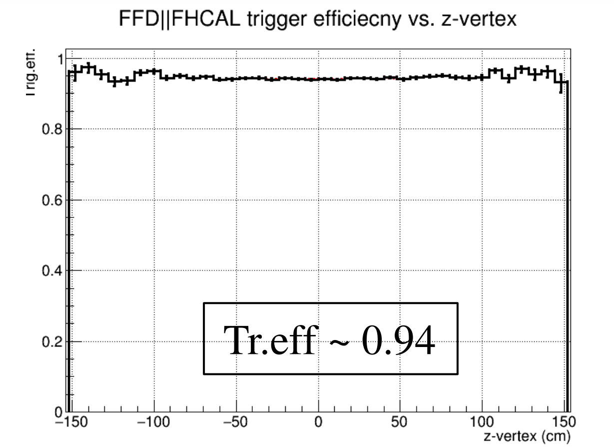
- MPD challenges at NICA energies:
  - ✓ low multiplicity of particles produced in heavy-ion collisions
  - ✓ particles are not ultra-relativistic (even the spectator protons)

Trigger efficiency vs. z-vertex

- DCM-QGSM-SMM, BiBi@9.2: trigger efficiency is 90-95% for different trigger configuration







- DCM-QGSM-SMM, CC@9.2: trigger efficiency < 50%; pp@9.2: efficiency vanishingly small
- The existing trigger system does not provide high enough efficiency in light A-A and pp collisions
- Need to develop another (additional) system on the basis of existing STAR event plane or ALICE V0:
  - ✓ evaluate design (distance in z from vertex, radius, segmentation)
  - ✓ build and test the prototypes

3. Further development of the MPD physics program with focus on new signals/observables which would be unique for the MPD

Summary

- ❖ Preparation of the MPD detector and experimental program is ongoing, all activities are continued
- ❖ All components of the MPD 1-st stage detector are in advanced state of production
- ❖ Commissioning of the MPD Stage-I detector and the first data taking with BiBi@9.2 in 2024


С НАСТУПАЮЩИМ
НОВЫМ
ГОДОМ!
С Новым Годом!

BACKUP

RHIC BES program

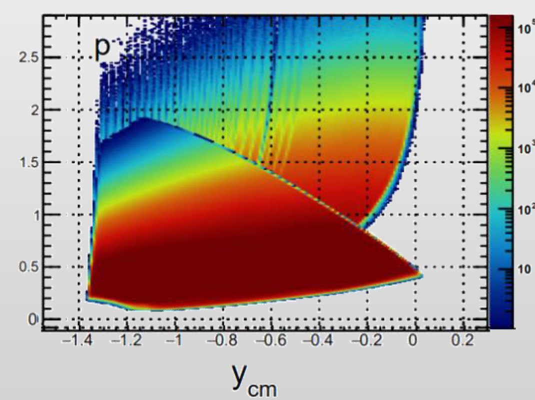
- Data taking by STAR at RHIC: $3 < \sqrt{s_{NN}} < 200$ GeV ($750 < \mu_B < 25$ MeV)

Au+Au Collisions at RHIC

Collider Runs						Fixed-Target Runs					
	$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run		$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run
1	200	380 M	25 MeV	5.3	Run-10, 19	1	13.7 (100)	50 M	280 MeV	-2.69	Run-21
2	62.4	46 M	75 MeV		Run-10	2	11.5 (70)	50 M	320 MeV	-2.51	Run-21
3	54.4	1200 M	85 MeV		Run-17	3	9.2 (44.5)	50 M	370 MeV	-2.28	Run-21
4	39	86 M	112 MeV		Run-10	4	7.7 (31.2)	260 M	420 MeV	-2.1	Run-18, 19, 20
5	27	585 M	156 MeV	3.36	Run-11, 18	5	7.2 (26.5)	470 M	440 MeV	-2.02	Run-18, 20
6	19.6	595 M	206 MeV	3.1	Run-11, 19	6	6.2 (19.5)	120 M	490 MeV	1.87	Run-20
7	17.3	256 M	230 MeV		Run-21	7	5.2 (13.5)	100 M	540 MeV	-1.68	Run-20
8	14.6	340 M	262 MeV		Run-14, 19	8	4.5 (9.8)	110 M	590 MeV	-1.52	Run-20
9	11.5	157 M	316 MeV		Run-10, 20	9	3.9 (7.3)	120 M	633 MeV	-1.37	Run-20
10	9.2	160 M	372 MeV		Run-10, 20	10	3.5 (5.75)	120 M	670 MeV	-1.2	Run-20
11	7.7	104 M	420 MeV		Run-21	11	3.2 (4.59)	200 M	699 MeV	-1.13	Run-19
						12	3.0 (3.85)	2000 M	750 MeV	-1.05	Run-18, 21

- A very impressive and successful program with many collected datasets, already available and expected results
- Limitations:
  - ✓ Au+Au collisions only
  - ✓ Among the fixed-target runs, only the 3 GeV data have full mid-rapidity coverage for protons (|y| < 0.5), which is crucial for physics observables

Au+Au @ 3.9 GeV



MPD strategy

- MPD strategy – high-luminosity scans in **<u>energy</u>** and **<u>system size</u>** 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 start, star mergers

- Scans to be carried out using the **<u>same apparatus</u>** in the same configuration/geometry 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.

- Work in close cooperation with theoreticians to look for new signals/observables including those unique for the MPD
  - ✓ direct photons
  - ✓ system size scan collective flow, strangeness enhancement
  - ✓ applied research → high energy heavy-ion reaction database, input for transport codes (Geant-4, Fluka, PHITS, etc)

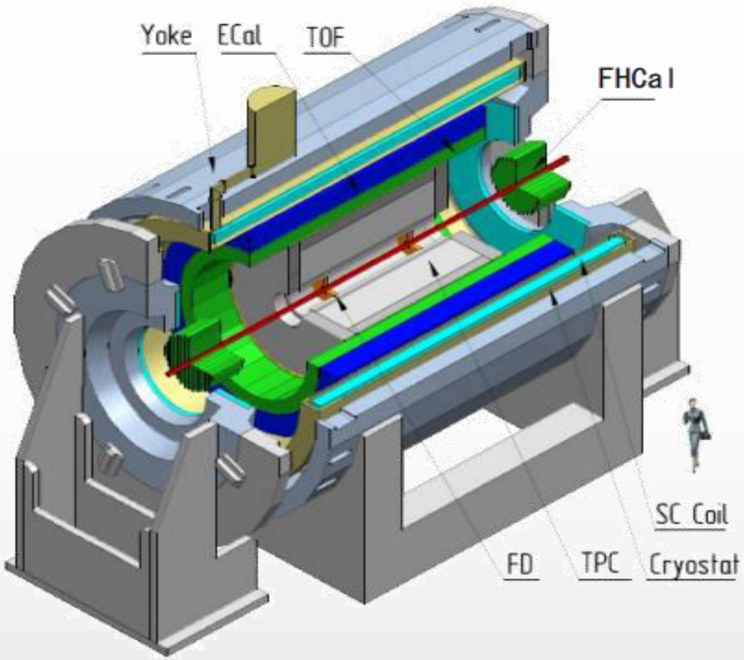
Multi-**P**urpose **D**etector (MPD) Collaboration

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

10** Countries, **>450** participants, **33** Institutes and **JINR

Organization

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



***Joint Institute for Nuclear Research**;*
*AANL, Yerevan, **Armenia;***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*IHEP, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
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*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
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*Belgorod National Research University, **Russia**;*
*INR RAS, Moscow, **Russia**;*
*MEPhI, Moscow, **Russia**;*
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