Proposal for continuation of the MPD project

V. Riabov for the MPD Collaboration

JOINT INSTITUTE FOR NUCLEAR RESEARCH

The Report on Project

"MPD. MultiPurpose Detector"

02-1-1065-3-2011/2025

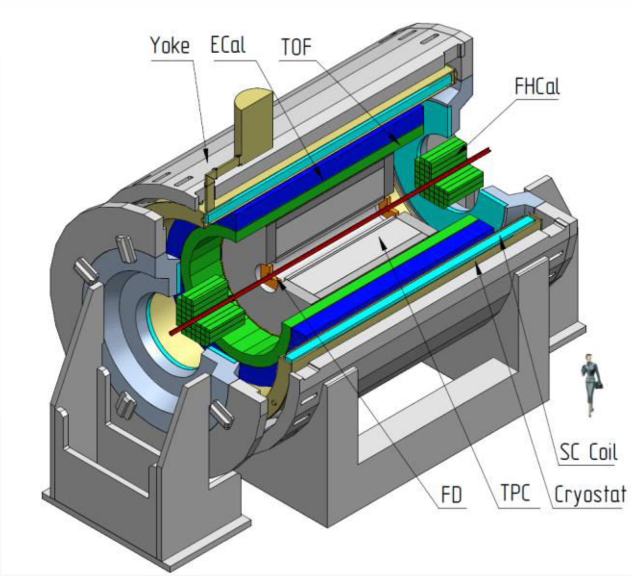
Feasibility study of the second stage of the MPD

<u>Theme: 02-0-1065-2007/2026</u>

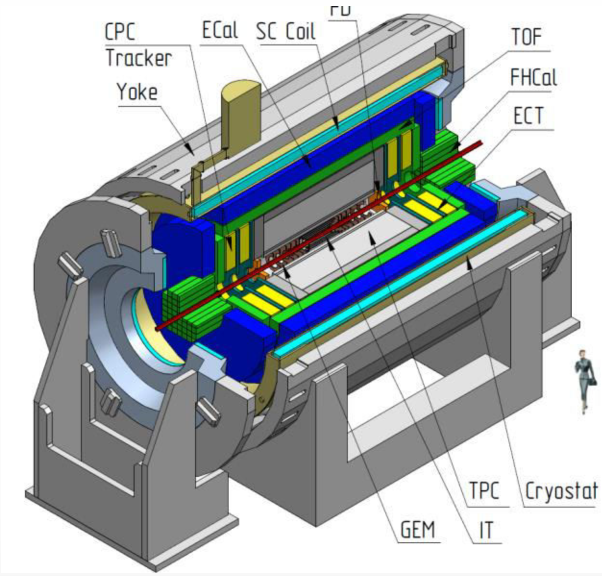
LEADER *V.M.Golovatyuk, V.D.Kekelidze, V.G.Riabov*

Multi-Purpose Detector (MPD)

Stage-I



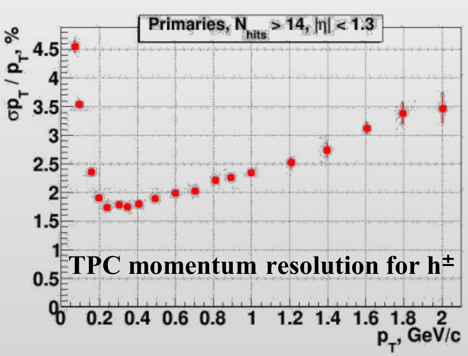
Stage-II

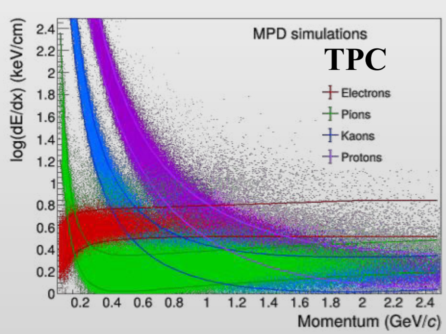


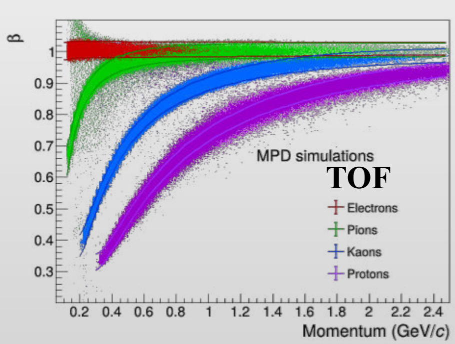
TPC: |Δφ| < 2π, |η| ≤ 1.6; **TOF, EMC**: |Δφ| < 2π, |η| ≤ 1.4
FFD: |Δφ| < 2π, 2.9 < |η| < 3.3; **FHCAL**: |Δφ| < 2π, 2 < |η| < 5

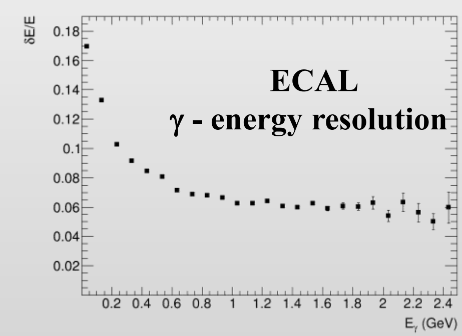
\+ **ITS** : |Δφ| < 2π, |η| ≤ 3
\+ **Forward Spectrometers**: |Δφ| < 2π, |η| ≤ 2.2

Au+Au @ 11 GeV (full event simulation and reconstruction)









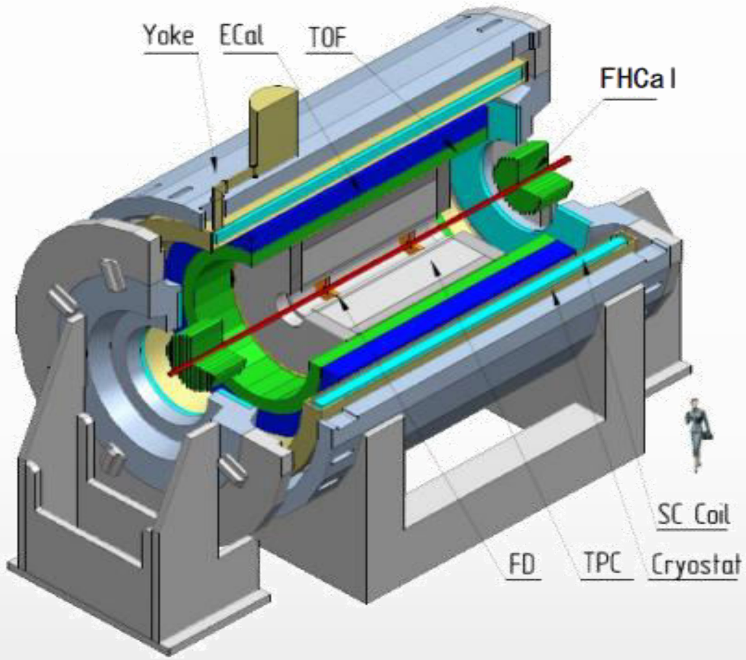
Multi-Purpose Detector (MPD) Collaboration

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

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

Organization

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

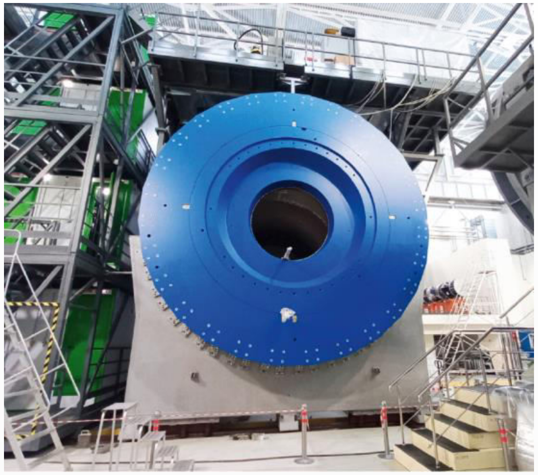


***Joint Institute for Nuclear Research, Dubna**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*SSI "Joint Institute for Energy and Nuclear Research – Sosny" of the National Academy of Sciences of Belarus, Minsk, **Belarus***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, 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***

MPD magnet

Magnet yoke

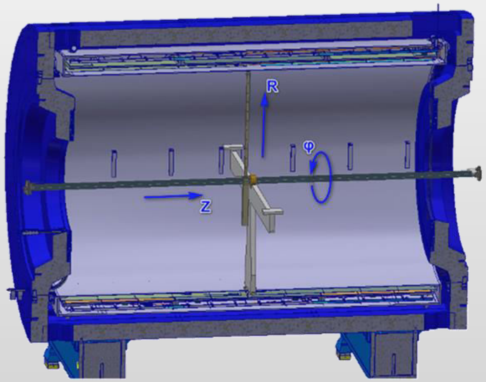


Cryogenic platform

Strings for cryogenic pipes and cables hold

- First cooling if the magnet to below LN2 temperature of ~ 70^0 K in February-March 2024
- Start of cooling to LHe temperature in October → cooled to 4.5^0 K in December 2024

Magnetic field mapper



Novosibirsk BINP magnetic field mapper

	Along radius (R)	Along azimuth angle (ϕ)	Along beam (z)
Step size, см	5	21	10
Total length, см	220	360° (1380 см at max. R)	700
Number of measurements	44	64	70

Single 3D Hall probe moves in 3 directions: z , R, ϕ
Accuracy: 0.1 – 0.3 Gs
Number of points: ~ $2{\cdot}10^5$ (90 hours)
Fields to measure: 0.3 – 0.57 T (5-6 points)
Number of tunes per field: 5
Total time of measurements: ~ 3-4 months

Assembly and tests in February, 2025

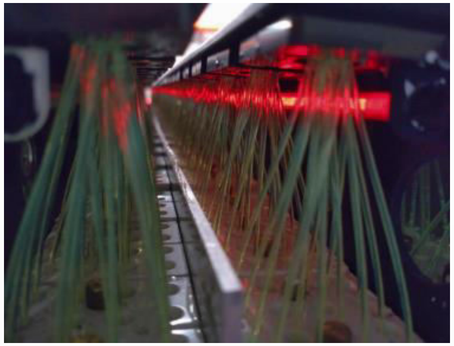
Cooling Water system needed to apply currents

Central barrel subsystems

Frame - ready

Carbon fiber support frame delivered and unpacked, sagita ~ 5 mm at full load, rails for the TPC and TOF are installed

ECAL



ECAL ~ 38400 towers (2400 modules) produced by Tsinghua University, Shandong University, Fudan University, South China University, Huzhou University and JINR – production in IHEP (Protvino) and Tenzor (Dubna)

83% of calorimeter modules (~2000) is ready, remaining baskets to be ready by April 2025

TOF - ready

All 28 (100%) TOF modules are assembled, tested, stored and ready for installation. Spare modules in production

TPC – central tracking detector

24+ ROC ready; 100+ % FE cards manufactured
TPC gas volume assembly and HV/leakage tests – ongoing
TPC + ECAL cooling systems under commissioning

TPC mechanical body assembly with ROCs, leak test and HV test	**May 2025**
TPC installation to MPD and test	**Sept –Nov 2025**

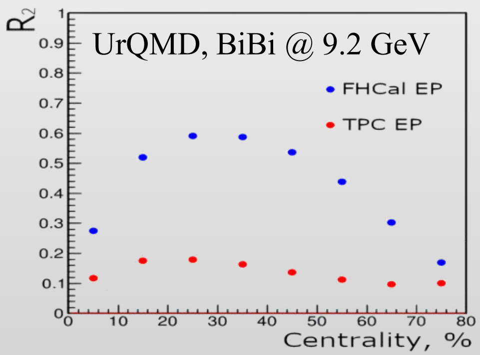
Forward subsystems

FHCAL - ready

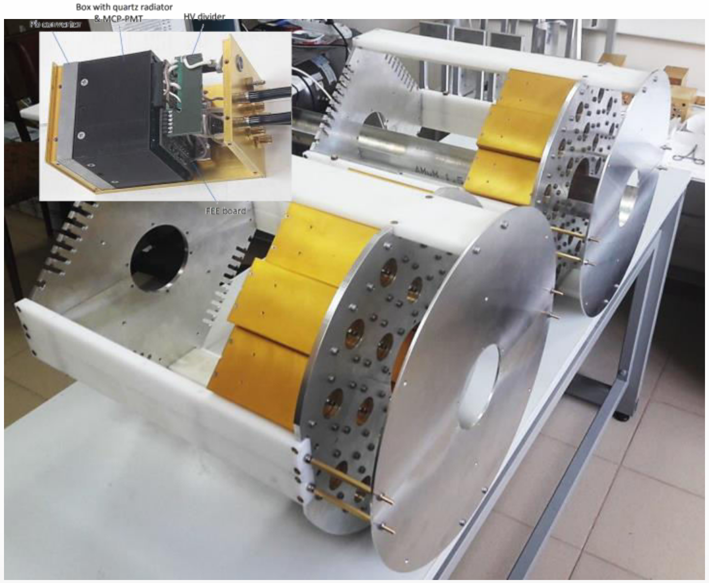
FHCal assembled on the platform, (modules are equipped with FEE)

Test installation of FHCAL → autumn 2024

FHCAL provides triggering information, centrality and event plane

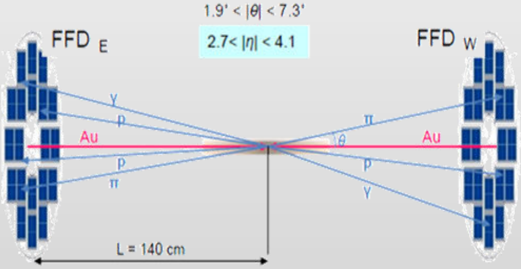


FFD - ready



Cherenkov modules of FFDE and FFDW, mechanics for installation in container with beam pipe are available, Long term tests with cosmic rays & laser ongoing

FFD provides triggering information, even z-vertex and T_0 for timing measurements



Main milestones in the last 6 months

- Completion of work on the installation of the Southern platform – Done
- Assembly of the second FHCal – Done
- Test installation of FHCal into a pole – Done
- Solenoid cable routing – Done
- Flushing (cleaning) the cooling system pipes – Done
- Restoring the shape of the frame – Done
- Installation of TPC rails – Done
- Test of the Tof Installation into Support Frame – Done
- Solenoid Cooling to the working temperature (4K) – Done

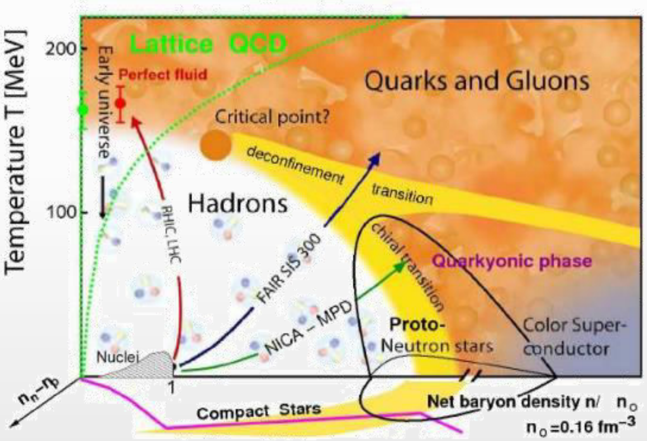
MPD schedule – 2025

1	January 13th- 30th	Solenoid and Correction Coils Power Supplies control system
2	January 20th – February 10th	Solenoid Safety regimes of emergent energy evacuation working out Development of algorithms of cooling on base of experience with manual regime
3	February 10 – February 25th	Cooling down of the Solenoid to the working temperature 4K
4	February 25th - March 10th	Installation Magnetic Field Mapper, Calibration, preparation for measurements of Field
5	March 10th - June 15th	Magnetic field measurements on nominals: 0.2T, 0.3T, 0.4T, 0,45T, 0.5T, 0,55T
6	May 30th	TPC mechanical body is assembled, leak test and HV test are finished
7	June 15th – June 20th	Support Frame installation
8	June 20th – July 20th	Installation FHCal into poles
9	June 22d – August 30th	Ecal installation
10	July 10th – August 30th	Installation TOF modules (access from both sides)
11	September 1st – November 23d	TPC installation
12	June 2d – November 30th	Cabling
13	December 4th – December 14th	Beam pipe installation
14	December 22d	Moving on the beam line
15	December 30th	Readiness for the Data taking

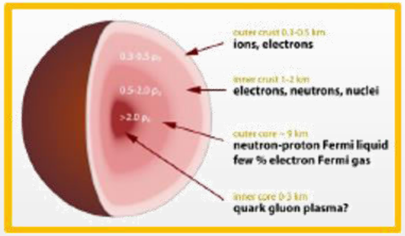
Starting detector commissioning in late 2025 remains the main priority

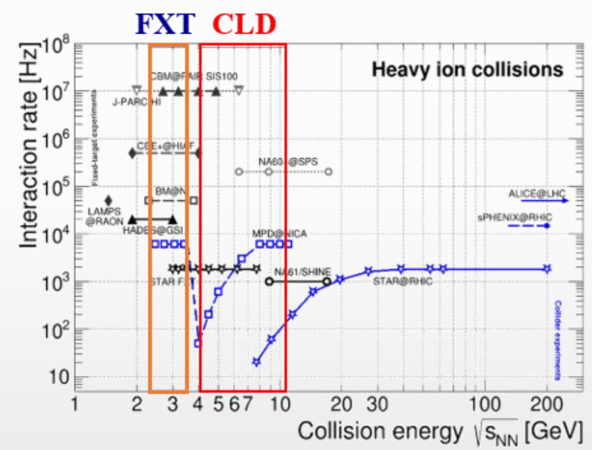
Physics feasibility studies

- Physics feasibility studies using centralized large-scale MC productions
- Centralized Analysis Framework for access and analysis of data → Analysis Train:
  - ✓ consistent approaches and results across collaboration, easy storage and sharing of codes
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes
- Heavily rely on the LIT and VBLHEP computing resources, thanks to computing and software teams!
- Develop physics program, software and analysis infrastructure for real data analysis



high baryon densities
→ inner structure of
compact stars





QCD medium at extreme net baryon densities → 1st order phase transition + CEP

- MPD-CLD and MPD-FXT approved start-up:
  - ✓ Collider mode: two beams, $\sqrt{s_{NN}}$ = 4-11 GeV
  - ✓ Fixed-target mode: one beam + thin wire (~ 50-100 μm) :
    - extends energy range to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (HADES, BM@N, CBM)
    - no problem of low event rate at lower collision energies

Scientific activity

- ~ 60 reports at international conferences per year
- Annual NICA Workshops organized by JINR-MEPhI
  https://indico.jinr.ru/event/4973/overview
- Totally 250+ publications (~30/year):

1. E. Nazarova [MPD Collaboration], Performance study of the hyperon global polarization measurements with MPD at NICA, Eur.Phys.J.A 60 (2024) 4, 85
2. A. Zinchenko [MPD Collaboration], A Monte Carlo Study of Hyperon Production with the MPD and BM@N Experiments at NICA, Particles 6 (2023) 2, 485-496
3. M. Mamaev [MPD Collaboration], Toward the System Size Dependence of Anisotropic Flow in Heavy-Ion Collisions at 2–5 GeV, Particles 2023, 6(2), 622-637
4. I. Segal [MPD Collaboration],, Centrality Determination in Heavy-Ion Collisions Based on Monte-Carlo Sampling of Spectator Fragments, Particles 2023, 6(2), 568-579
5. A. Zinchenko, A Monte Carlo Study of Hyperon Production with the MPD and BM@N Experiments at NICA, Particles 2023, 6(2), 485-496
6. D. Peresunko [MPD Collaboration], Direct Photon Production in Heavy-Ion Collisions: Theory and Experiment, Particles 2023, 6(1), 173-187
7. V. Kondratyev [MPD Collaboration], Identification Capability of the Inner Tracking System for Detecting D Mesons at the NICA-MPD Facility, Bull.Russ.Acad.Sci.Phys. 86 (2022) 8, 1005-1009
8. V. Kolesnikov [MPD Collaboration], Monte Carlo Studies of the MPD Detector Performance for the Measurement of Hypertritons in Heavy-Ion Collisions at NICA Energies, Phys.Part.Nucl.Lett. 19 (2022) 1, 46-53
9. O. Rogachevsky [MPD Collaboration], Software Development and Computing for the MPD Experiment, Phys.Part.Nucl. 52 (2021) 4, 817-820
10. V. Riabov [MPD Collaboration], Production and reconstruction of short-lived resonances in heavy-ion collisions at NICA energies using the MPD detector, Phys.Scripta 96 (2021) 6, 064002

Collaboration papers

I. Status and initial physics performance studies of the MPD experiment at NICA
Eur.Phys.J.A 58 (2022) 7, 140 (~ 50 pages)

II. MPD physics performance studies in Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV
consolidation and publication of physics feasibility studies for BiBi@9.2 GeV

1. Introduction
2. MPD setup
3. Data analysis framework
   - 3.1 Event generators and centralized productions
   - 3.2 Analysis Train Framework
4. Global event categorization
   - 4.1 Trigger system and efficiency
   - 4.2 Event centrality
   - 4.3 Event plane
5. Physics performance studies
   - 5.1 Light flavor hadron production
     - 5.1.1 Yields of charged pions, kaons and (anti)protons
     - 5.1.2 Hyperon reconstruction
     - 5.1.3 Short-lived hadronic resonances
     - 5.1.4 Hyperon global polarization
   - 5.2 Light nuclei
     - 5.2.1 Light nuclei production
     - 5.2.2 Hypernuclei
   - 5.3 Anisotropic flow
   - 5.4 Femtoscopy and correlations
     - 5.4.1. Femtoscopic correlations of charged pions
     - 5.4.2 Charged balance function
   - 5.5 Electromagnetic signals and neutral mesons
     - 5.5.1 Photons
     - 5.5.2 Differential p_T spectra for π^0 and η mesons
     - 5.5.3 Collective flow of inclusive photons and mesons
     - 5.5.4 Dielectrons
6. Conclusions

Paper draft just passed first collaboration and IRC reviews → to be submitted by the CM
(https://mpdforum.jinr.ru/t/ppg002-first-collaboration-review/674/9 – 40+ pages)

Continuation of the MPD project

Cost estimation

Proposed schedule and resource request for the MPD Project

Expenditures, resources, funding sources			Cost (thousands of US dollars)/ Resource requirements	Cost/Resources, distribution by years				
				1st year	2nd year	3rd year	4th year	5th year
		International cooperation	1000	200	200	200	200	200
		Materials	23350	3700	5250	6500	5350	2550
		Equipment, Third-party company services	6450	1100	1150	1850	1550	800
		Commissioning	300	0	50	100	100	50
		R&D contracts with other research organizations	450	100	100	100	100	50
		Software purchasing						
		Design/construction						
		Service costs *(planned in case of direct project affiliation)*	1000	200	200	200	200	200
Resources required	Standard hours	Resources						
		- the amount of FTE,	625	125	125	125	125	125
		- accelerator/installation,	13720	2200	2880	2880	2880	2880
		- reactor,…						
Sources of funding	JINR Budget	JINR budget *(budget items)*	**33000**	**5400**	**7050**	**9050**	**7600**	**3900**
	Extra funding (supplementary)	Contributions by partners	500	100	100	100	100	100
		Funds under contracts with customers						

Project Leader ____ V.M.Golovatyuk

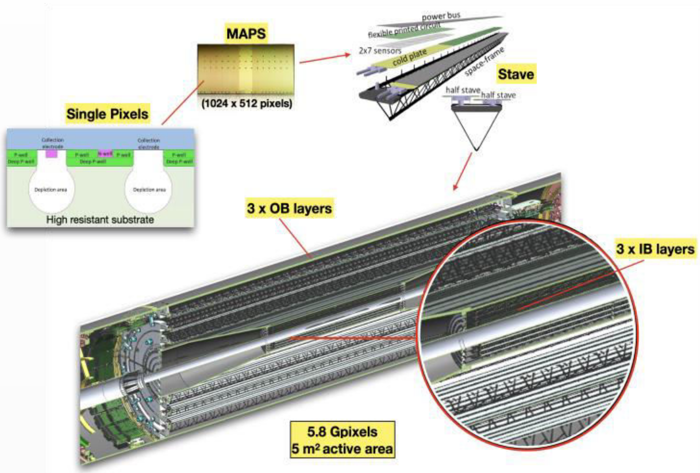
Laboratory Economist ____ V.V.Morozov

Resources distribution by years

The main systems, resources, funding souces			Cost of the main subsystems (k$)	Cost/Resources distributiom by years (k$)				
				1 y. (2026)	2 y. (2027)	3 y. (2028)	4 y. (2029)	(2030)
Resources required	The main systems	Time Projection Chamber upgrade (TPC)	5250	700	1200	1650	1000	700
		Upgrade of Ecal	700	200	200	100	100	100
		Upgrade of FHCal	350	100	100	50	50	50
		Upgrade of Forward FFD	250	50	50	50	50	50
		Cryogenic and Power Supply systems of Magnet	3500	1100	900	800	500	200
		Upgrade of DAQ	850	150	150	200	200	150
		Infrastructure of the MPD	900	250	250	200	100	100
		Second stage detectors						
		Forward TOF	3770	420	750	1100	1100	400
		Forward Ttracker	13140	1350	2850	3650	3450	1840
		Inner Tracker (ITS)	4290	1270	1050	1200	700	70
		Total:	**33000**	**5590**	**7500**	**9000**	**7250**	**3660**
		International Cooperation	825	165	165	165	165	165

Inner Tracking System – ITS

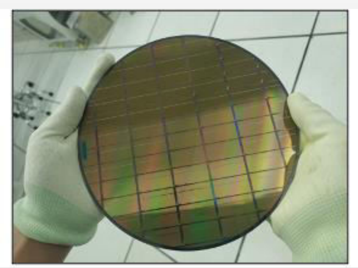
The ITS is the key to measuring the production of heavy-flavor hadrons



The complete structure of the 6-layer MPD-ITS detector, from a single pixel to the inner and outer cylindrical layers

1) The TDR was finalized to build an ITS consisting of six cylindrical layers of MAPS (Monolithic Active Pixel Sensors) around the interaction region: 3 layers of inner barrel (IB) surrounded by 3 layers of outer barrel (OB)

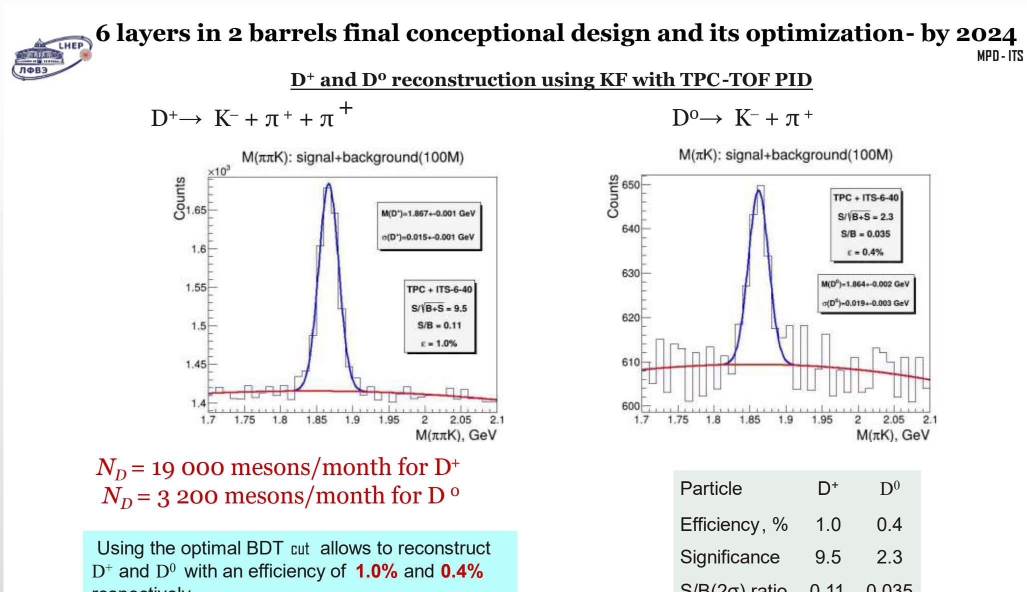
2) An agreement was reached with Chinese partners to jointly research, develop and manufacture in China the missing components needed to build the tracker and its readout system.



- first prototype of ALPIDE-like MAPS (MICA) sensor developed at CCNU and produced in China

- FPGA-based Readout System and the Power Unit developed at USTC for reading out the "staves" comprising of MICA sensors of IB and OB → tests at LHEP in 2025

- first porotypes of the GBT ASICs for the fast aggregation of data and transfer via optical lines designed and manufactured → lab tests ongoing in CCNU.



Particle	D^+	D^0
Efficiency, %	1.0	0.4
Significance	9.5	2.3
S/B(2σ) ratio	0.11	0.035

D^0 and D^+ reconstruction using information from ITS+TPC+TOF subsystems

Rapidity scan with MPD at NICA

More detailed study of the QCD phase diagram by utilizing a three-dimensional scan in collision energy, interacting system size, and particle rapidity

Rapidity dependence of cumulant observables can enhance the prospect of discovering a CEP

J.Li, L.Du and S.Shi, Rapidity scan approach for net-baryon cumulants" Phys. Rev. C 109, no.3, 034906 (2024)
J. Brewer et al., Phys. Rev. C 98, 061901 (2018)

Rapidity-dependent yields offers an extra method to explore the EoS at finite chemical potentials.

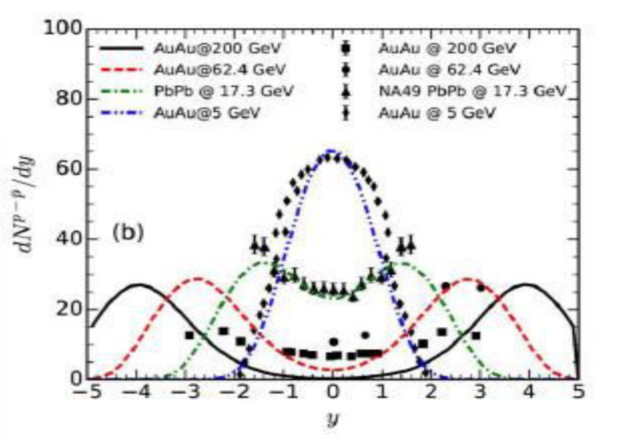
L.Du,`Bulk medium properties of heavy-ion collisions from the beam energy scan with a multistage hydrodynamic model," Phys. Rev. C 110 (2024) no.1, 014904

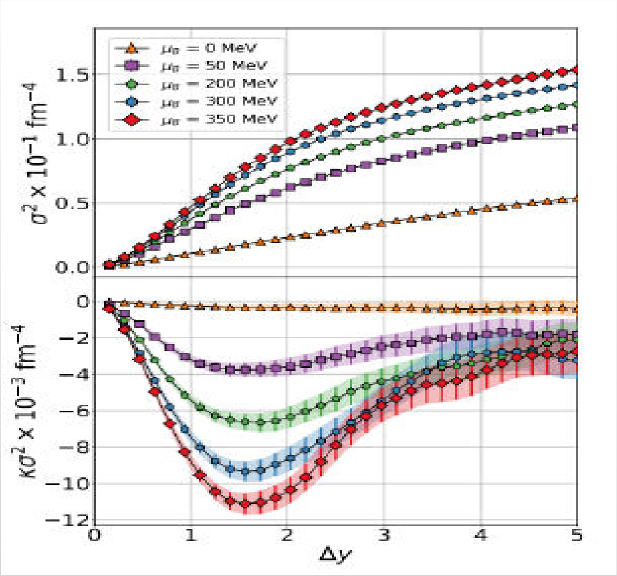
Thermodynamic properties, especially the baryon chemical potential (μ_B), undergo significant variations across rapidity,

L.Du, H.Gao, S.Jeon and C.Gale, Rapidity scan with multistage hydrodynamic model, Phys. Rev. C 109, no.1, 014907 (2024)

Rapidity dependence of anisotropic flow provides provides sensitivity to (T,μ_B) dependence of specific shear (η/s) and bulk (ζ/s) viscosities

S.A.Jahan, H.Roch and C.Shen, Bayesian analysis of (3+1)D relativistic nuclear dynamics with the RHIC data, Phys.Rev.C 110 (2024) 5, 054905





International discussions

https://indico.jinr.ru/event/4642/

Discussed MPD upgrade options:

1. Construction of the ITS
2. Forward tracker and TOF-PID (~ 40 ps with pico-TDC chips)
3. Decrease TPC material budget in the forward direction (cables, electronics reorganization), upgrade of ROC proportional chambers to MPGDs (GEM, Micromegas)
4. Upgrade of ECAL electronics for better time resolution (~ 50 ps) and triggering capabilities

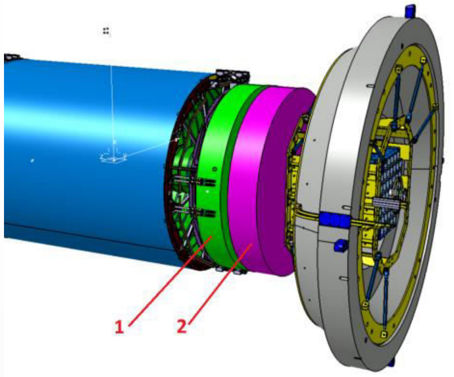
Motivation for Forward upgrade:

1. Full yields of (heavier) identified hadrons and light nuclei with non-trivial rapidity dependence due to baryon stopping, more detailed study of the "horn", the "step" effects for lighter hadrons
2. Two-particle correlation and multiparticle cumulant studies with wider coverage in $\Delta\eta$
3. Directed and elliptic flow → tighter constraints on η/s
4. Search for CEP with event-by-event fluctuations of conserved charges → higher sensitivity with wider rapidity coverage
5. Hyperon global polarization vs rapidity → insights on the origin of the global polarization signal, tighter constraints for models
6. Extended forward rapidity coverage may be beneficial for diffractive studies in proton-proton collisions, such as instanton searches
7. Improved trigger efficiency, centrality and event plane determination

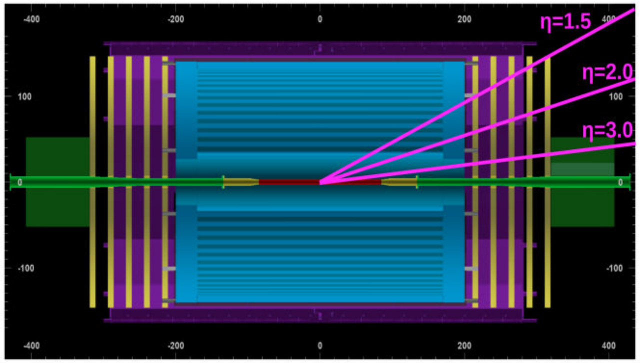
… and more

Plan to hold the next Workshop and to continue discussion in JINR this year

Forward spectrometers – tracking



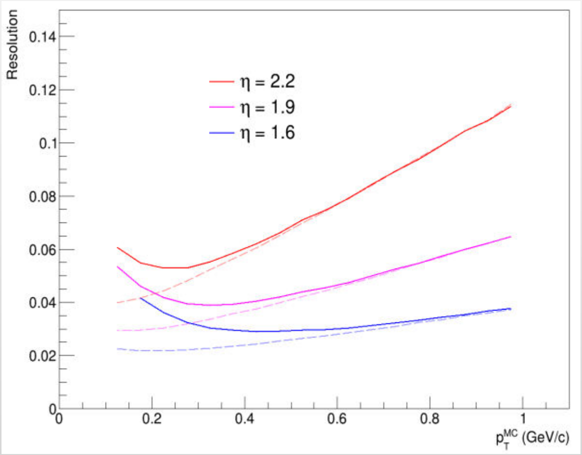
Two volumes (green and magenta) available for the installation of forward tracker stations

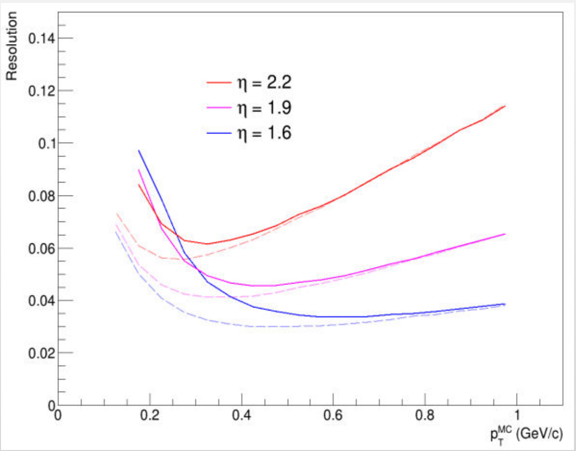


Pseudorapidity coverage of the forward spectrometer

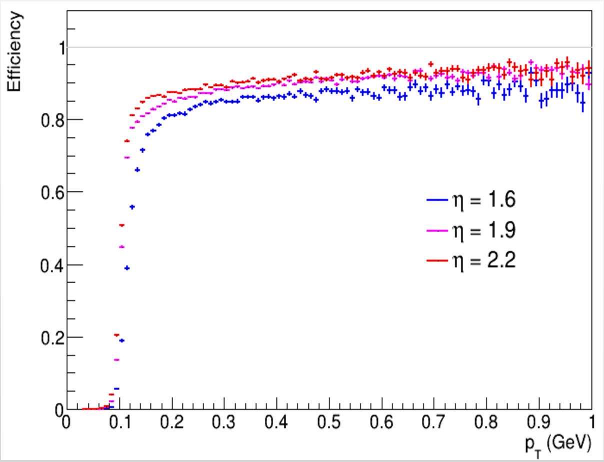
- Five tracking layers within z = 210–300 cm, 1% X_0, ~ 80 μm spatial resolution
- Tracking – ACTS package – experiment-independent high-level track reconstruction toolkit, including seeding tools and combinatorial Kalman Filter for track finding and vertex reconstruction

Momentum resolution for pions (left) and protons (right) at different η





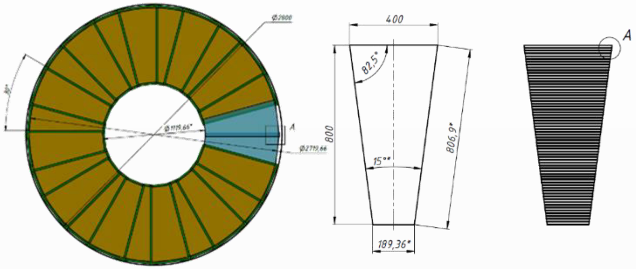
Tracking efficiency at different η



Forward spectrometers – PID

❖ Last layer is a TOF detector built of MRPC chambers

End-cap TOF detector(s)



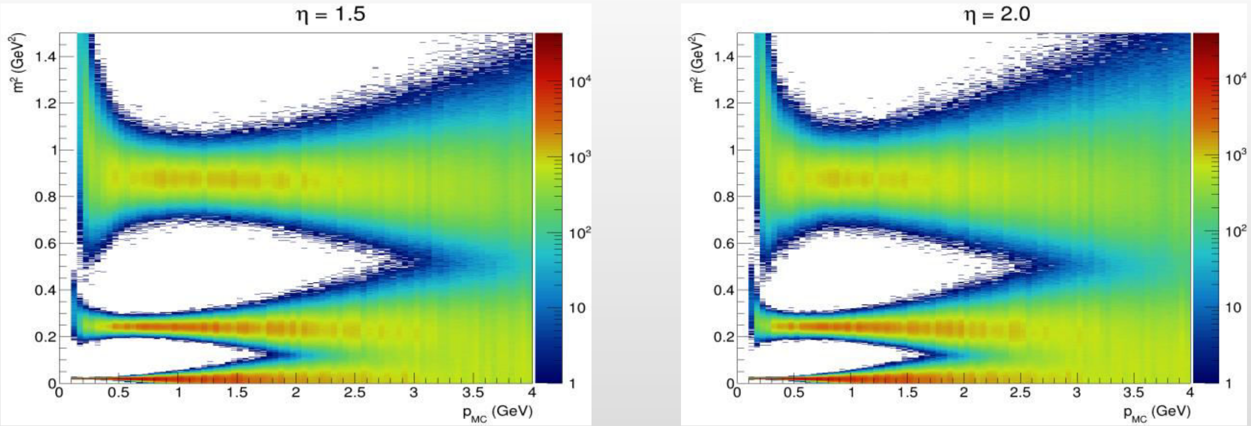
End-cap TOF ring design based on a trapezoidal MRPCs

Each MRPC chamber contains 64 strips, which both-sides read-out

Each TOF ring contains 24 MRPCs → 6144 read-out channels in total

Same electronics based on NINO and HPTDC chips as in the basic TOF-MPD

❖ Reliable π/K/p separation vs. particle momentum for different rapidity ranges



Rather limited momentum resolution is compensated by a large path length (~3m) → reasonable PID for charged hadrons

Summary

MPD Collaboration meeting in JINR (Dubna): October 14-16, 2024

- ❖ Construction of the MPD detector and infrastructure is advancing → start of MPD commissioning in late 2025 remains the main priority
- ❖ Develop physics program, software and analysis infrastructure for real data analysis
- ❖ Compiled a "Proposal for continuation of the MPD project", asking for approval

BACKUP

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

❖ Cross-PWG format of meetings for discussion of results and analysis techniques

Computing resources

MICC resource requirements

Computing resources	Distribution by year				
	2026	2027	2028 год	2029	2030
Data storage (TB) - EOS - Tapes	3 000 6 000	6 000 12 000	8 000 16 000	10 000 20 000	12 000 24 000
Tier 1 (CPU core hours)	3 500 000	5 000 000	9 000 000	9 000 000	9 000 000
Tier 2 (CPU core hours)	3 000 000	4 000 000	7 500 000	8 000 000	8 000 000
SC Govorun (CPU core hours) - CPU - GPU	800 000 -	1 000 000 -	3 000 000 -	1 000 000 -	3 000 000 -
Clouds (CPU cores)	0	0	0	0	0