Nuclotron based Ion Colider fAcility

Статус эксперимента MPD-NICA

В. Рябов, ЛРЯФ ОФВЭ

Nuclotron-based Ion Collider fAcility (NICA)

- Heavy-ion beams, fixed-target and collider (up to Au, $\mathcal{L} = 10^{27}$ cm^{-2}s^{-1}, $\sqrt{s_{NN}}$= 2.4-11 GeV) → strongly-interacting matter at extreme conditions of maximum baryonic density

Ion sourse (KRION-6T)
Heavy Ion Linac (HILac)
Booster

BM@N (Detector)
MPD (Detector)

- Polarized beams of protons and deuterons in the collider (up to $\mathcal{L} = 10^{32}$ cm^{-2}s^{-1}, $\sqrt{s_{NN}}$= 12.6 (d) 27 (p) GeV)
  → nucleon spin structure research and clarification of the spin origin

LU-20
Nuclotron

SPD (Detector)

- Applied Research Infrastructure for Advanced Developments at NICA fAcility (ARIADNA)
  → beam channels and irradiation stations for applied research with heavy-ion beams

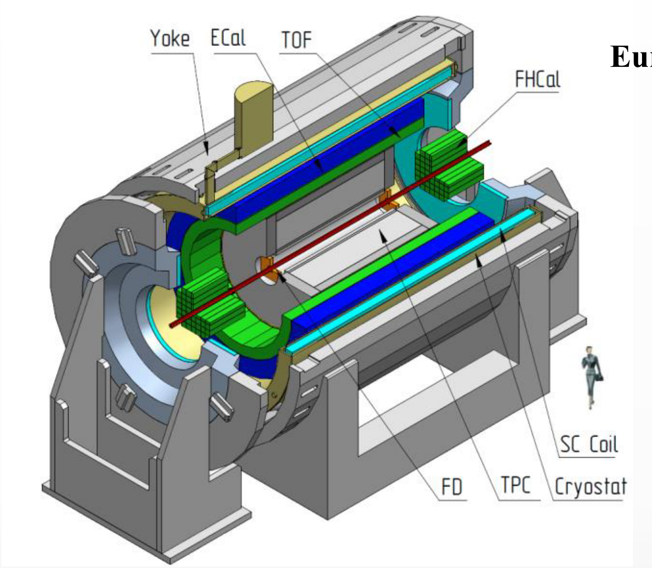
- NICA project is approaching its full commissioning:
  - ✓ already running in fixed-target mode – BM@N, ARIADNA
  - ✓ start of operation in collider mode in 2026 – MPD and later SPD

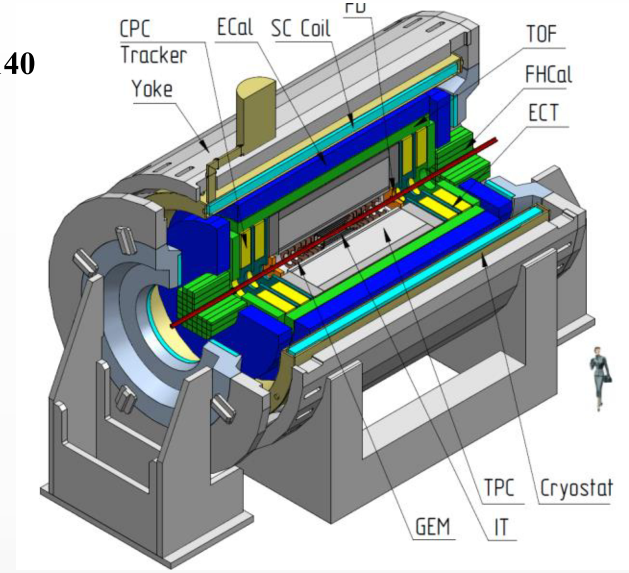
Multi-Purpose Detector

Stage-I → start of commissioning in 2025

Stage-II → 2030+

Eur.Phys.J.A 58 (2022) 7, 140

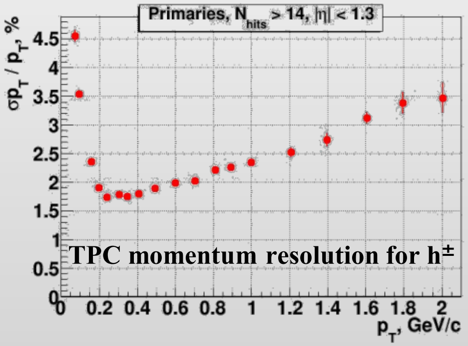


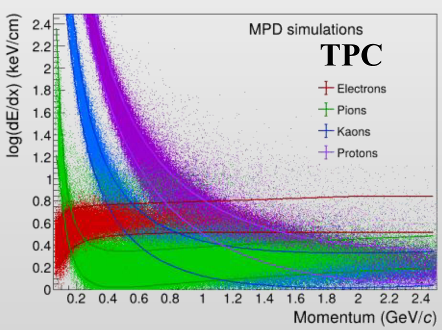


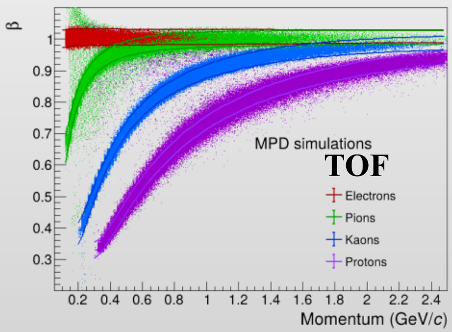
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$; **TOF, EMC**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$; **FHCAL**: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

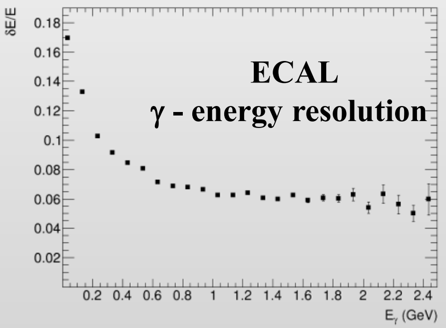
+ **ITS** : $|\Delta\varphi| < 2\pi$, $|\eta| \leq 3$
+ **Forward Spectrometers**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 2.2$

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



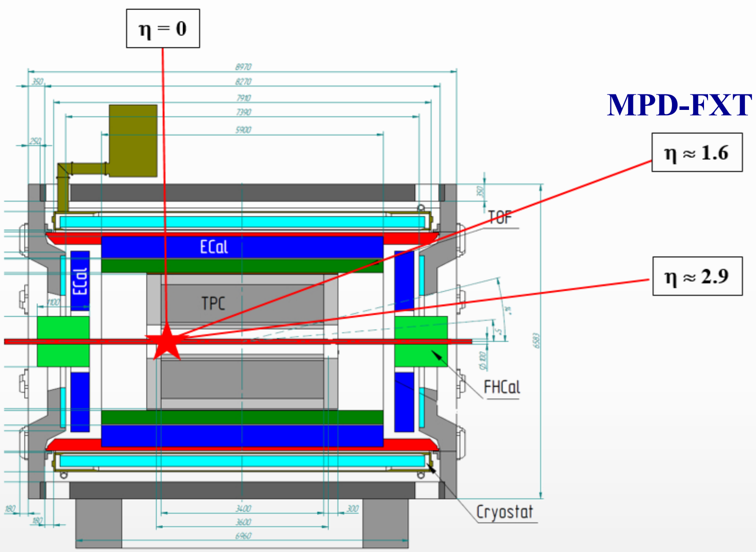


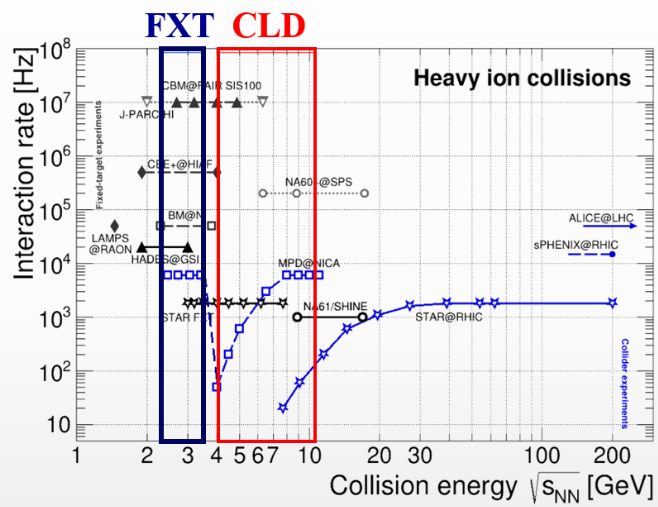




MPD strategy

- ❖ High-luminosity scans in **energy** and **system size** to measure a wide variety of signals
- ❖ Scans to be carried out using the **same apparatus** with all the advantages of collider experiments
- ❖ MPD-CLD and MPD-FXT operation modes approved from start-up:





competitors:

Present:

RHIC/STAR (USA)
3-200 GeV

SIS18/HADES (Germany)
2.4-2.55 GeV

Future:

HIAF/CEE (China)
2.1-4.5 GeV (2026-?)

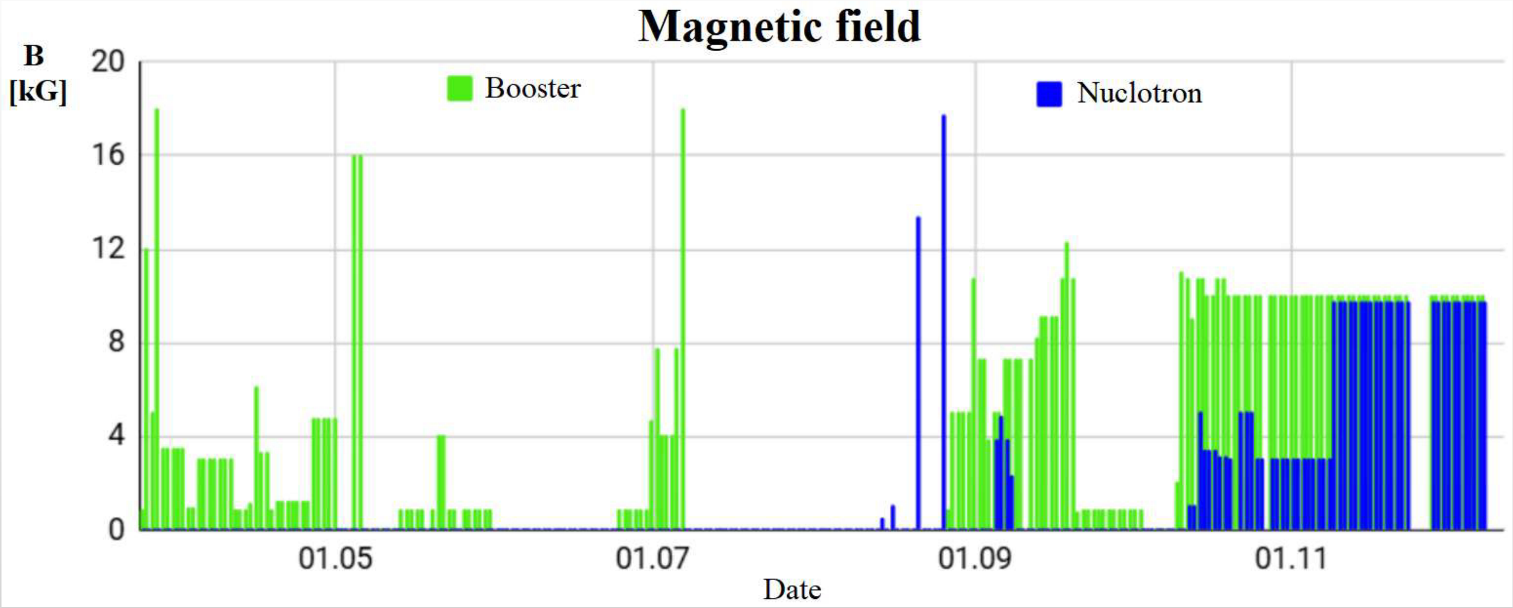
FAIR/CBM (Germany)
2.4-4.9 GeV (2029-?)

JPARC-HI (Japan)
2-5 GeV (2030-?)

- ✓ Collider mode: two heavy-ion beams, $\sqrt{s_{NN}}$ = 4-11 GeV
- ✓ Fixed-target mode: one beam + thin wire as a target (~ 50-100 μm) :
  - o extends energy range to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N, CBM)
  - o high event rate at lower collision energies

Injector modernization & commissioning

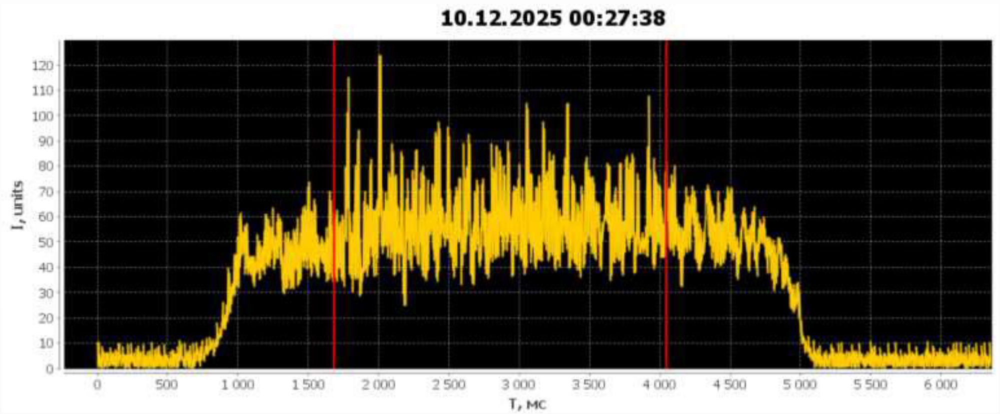
- Goals and Actions in Injection Complex upgrade:
  - ✓ increase heavy ion flux by x10 compared to the 2022-23 Run: Xenon ions: $(5\text{-}10)\cdot10^6 \rightarrow (2\text{-}5)\cdot10^8$
- Means:
  - ✓ beam accumulation in Booster (10 pulses with up to 10 Hz) and Nuclotron
  - ✓ drastic decrease of beam loss (stripping): (5 - 10)% → (80 - 90)%
- Already completed actions:
  - ✓ modernization of ion source
  - ✓ modernization of HILAC power supplies for higher repetition rate
  - ✓ orbit correction: done - in Booster, in process – in Nuclotron
  - ✓ optimized magnetic cycle: B(t) is designed to avoid beam loss due to reduction of RF bucket size in acceleration
  - ✓ multiple improvements in instrumentation & diagnostics
- Painful and long Nuclotron recommissioning:
  - ✓ multiple software and hardware problems: kickers, power supplies, synchronization, BPMs, …



Nuclotron extraction and transport lines

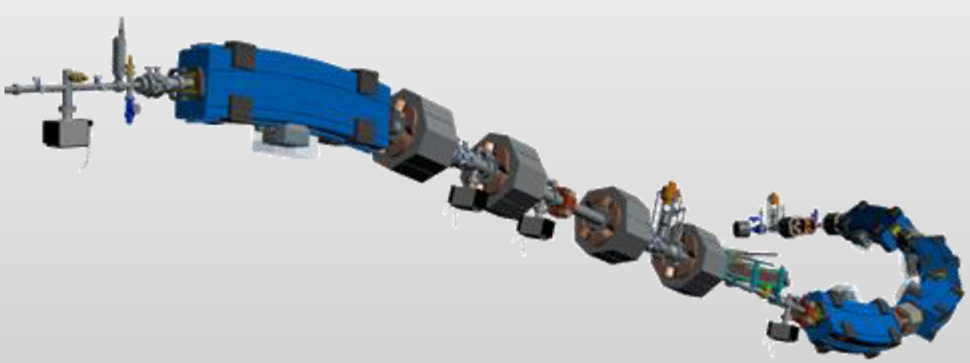
❖ Slow extraction:

- ✓ final stage of readiness for the beam delivery to BM@N
- ✓ imminent BM@N run in the beginning of 2026, energy scan with Xe beam



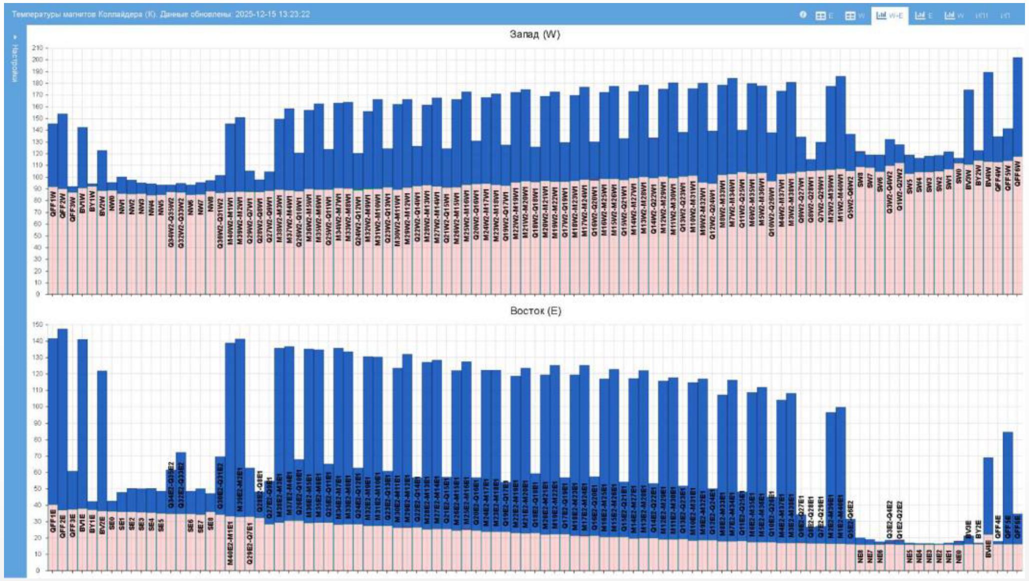
❖ Fast extraction & transport line:

- ✓ fast extraction from Nuclotron to collider was demonstrated
- ✓ transfer lines to the collider are assembled
- ✓ beam was threaded through the north branch, injection into collider through the north and south lines



NICA collider

❖ Although slower than it was expected, the NICA collider construction has proceeded relatively well



❖ First beam injection last week (no B filed yet)

❖ Arcs should be at LH temperature this week, tests of magnetic system will follow immediately

❖ Beam circulation very beginning of next year

Accelerator plans

- Beam delivery to BM@N at the beginning of next year → second physics run (Xe)

- Next steps – as conditions enable
  - ✓ initial commissioning of collider ring:
    first turns, BPMs, orbit correction, optics correction if required, circulation, RF system and synchronization …
  - ✓ obtained beam intensity in the injection complex is sufficient to support operation at the design luminosity at 2.5 GeV/n - chosen for the collider commissioning and initial operation
  - ✓ continuation of injection complex commissioning:
    optimization of beam accumulation, search of best operating tunes, 2nd RF harmonic, reduction of beam loss

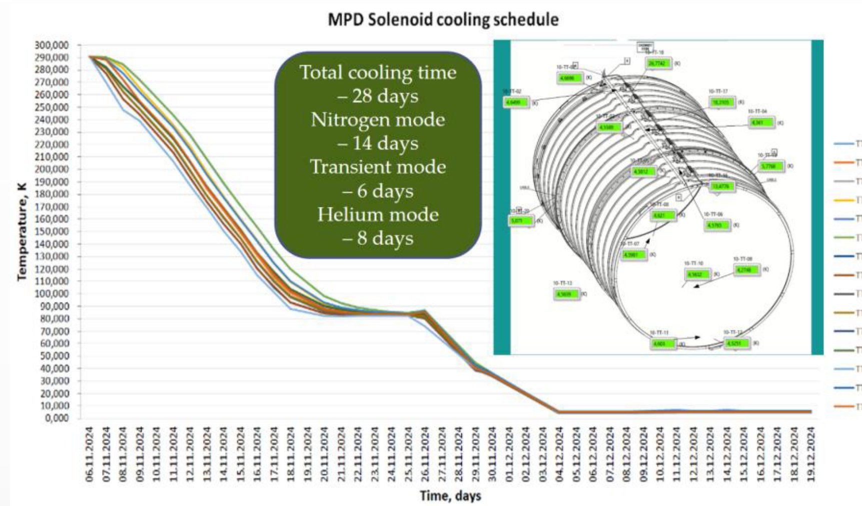
- Long 2026 summer shutdown:
  - ✓ ending construction work in bldg. 17
  - ✓ fix MANY problems we already got on the way
  - ✓ installation of RF and cooling systems

MPD superconducting magnet

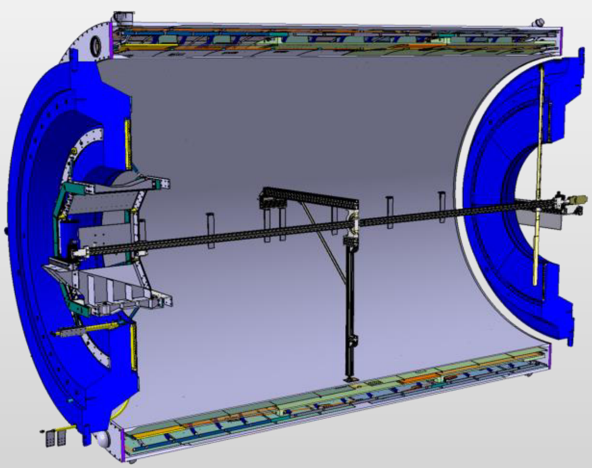
- Cooling of the magnet to LN2 and LHe temperatures → SC coil training up to 0.3 T

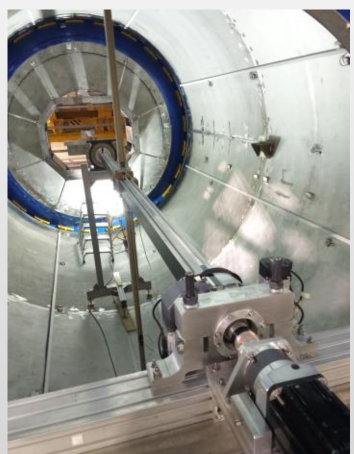
Magnet yoke and cryogenic platform

Cooling procedure and rate



- Magnetic field measurements: starting …





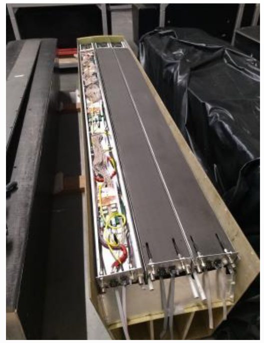
Single 3D Hall probe moves in 3 directions: z , R, ϕ
Accuracy: 0.1 – 0.3 Gs
Number of points: ~ $2{\cdot}10^5$ (90 hours)
Fields to measure: 0.3 – 0.57 T (5-6 points)
Number of tunes per field: 5
Total time of measurements: ~ 3-4 months

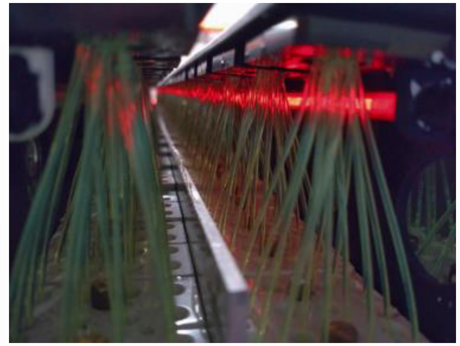
Central barrel subsystems

Frame - ready

Successful test installation of the carbon fiber support frame in the magnet, sagita ~ 5 mm at full load, rails for the TPC and TOF are installed

ECAL





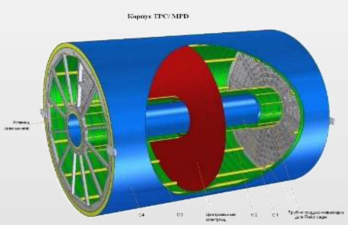
ECAL ~ 38400 towers (2400 modules)
produced by Tsinghua University, Shandong University, Fudan University, South China University, Huzhou University and JINR – production in IHEP (Protvino) and Tenzor (Dubna)

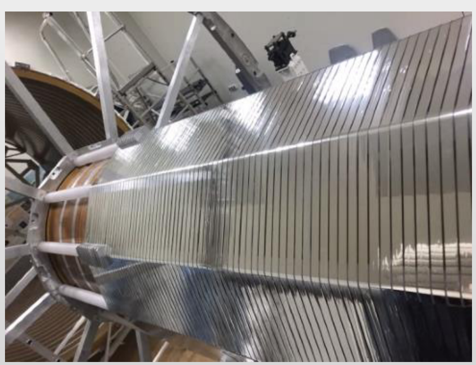
45 (50 in total) half-sectors to be ready by December (April)

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

Ongoing TPC gas volume assembly and HV/leakage tests

TPC + ECAL cooling systems under commissioning

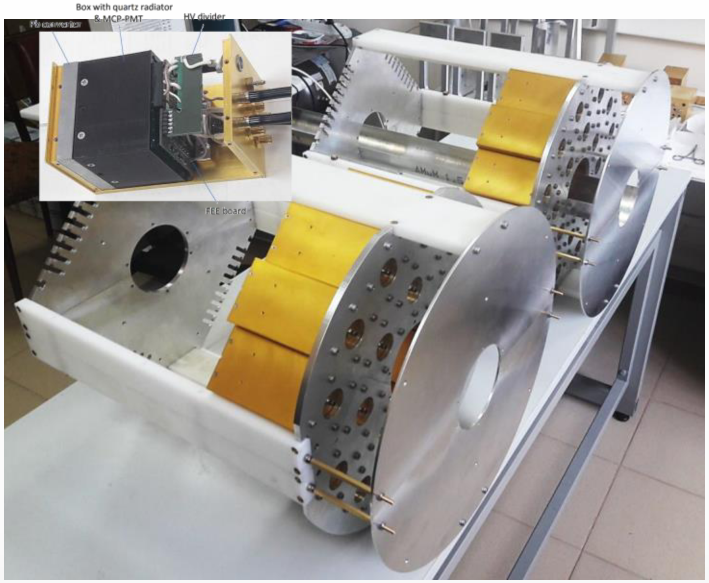
Forward subsystems

FHCAL - ready

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

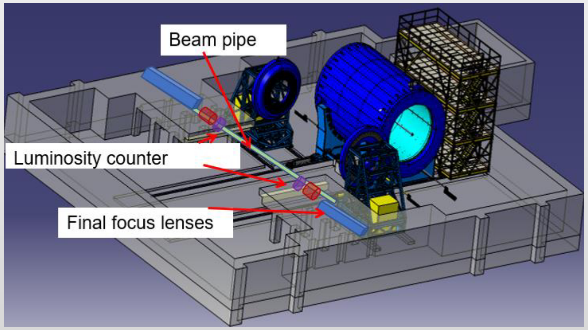
Test installation of FHCAL → autumn 2024
Final installation → Autumn 2025

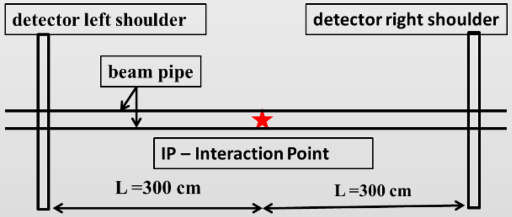
FFD - ready



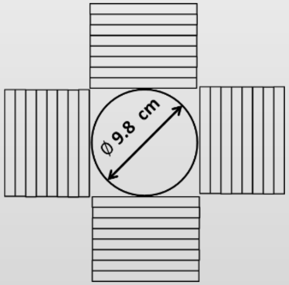
Cherenkov modules of FFDE and FFDW, mechanics for installation in container with beam pipe are available, Long term tests with cosmic rays & laser ongoing

Beam and luminosity monitoring



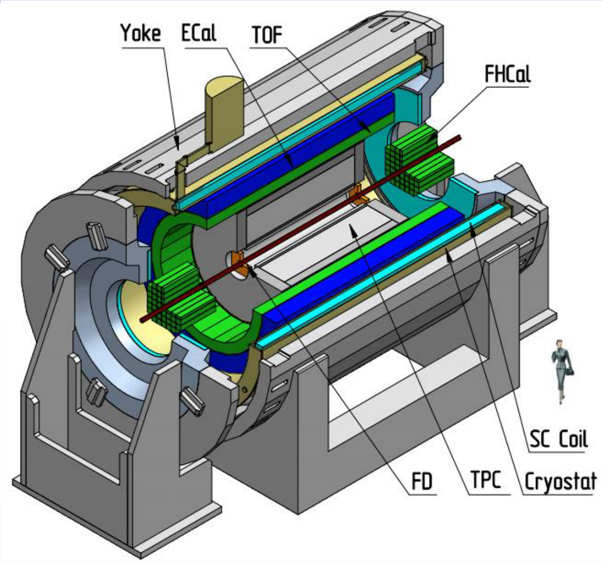


Measurement of transverse sizes of the bunches
Transvers and longitudinal convergence of bunches
Vertices distribution along the beam

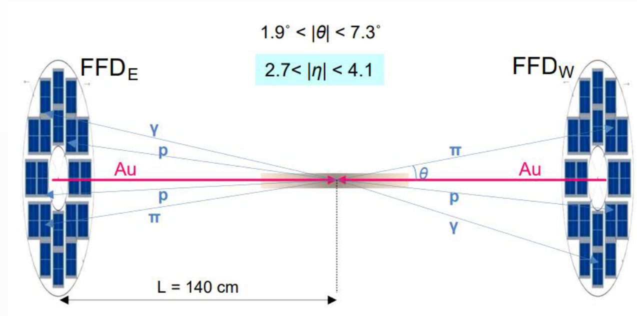


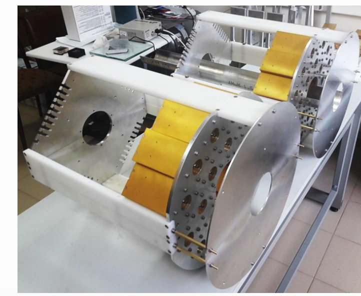
Assembly of the main components of the detector for the Run on the collider beam – end of 2025

Trigger system

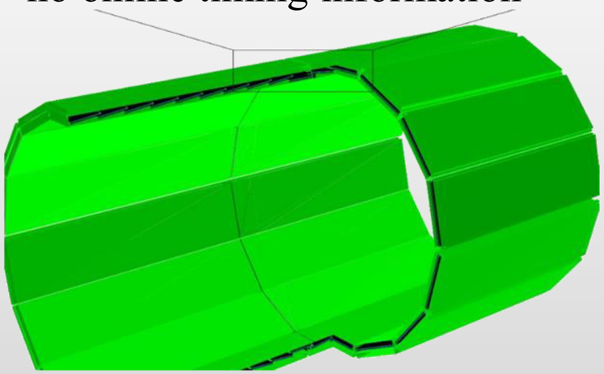


- FFD (Fast Forward Cherenkov Detector):
  - ✓ fast (~ 50 ps) event triggering → photons from π^0's
  - ✓ T_0 for time-of-flight measurements (TOF and ECAL)





- TOF (|η| < 1.5):
  - ✓ 280 fast signals for each MRPC chamber
  - ✓ no online timing information



- FHCAL (Forward Hadron Calorimeter):
  - ✓ Fast signals for event triggering
  - ✓ poor T_0 (~ 1 ns) and event z-vertex resolution

two FHCAL detectors
at 2 < |η| < 5,
~ 1x1 m^2 each

Trigger system of the MPD is effective for <u>different HI collision systems and energies</u> as well as for <u>different operation modes</u> (MPD-CLD vs. MPD-FXT)

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. Kireev, 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

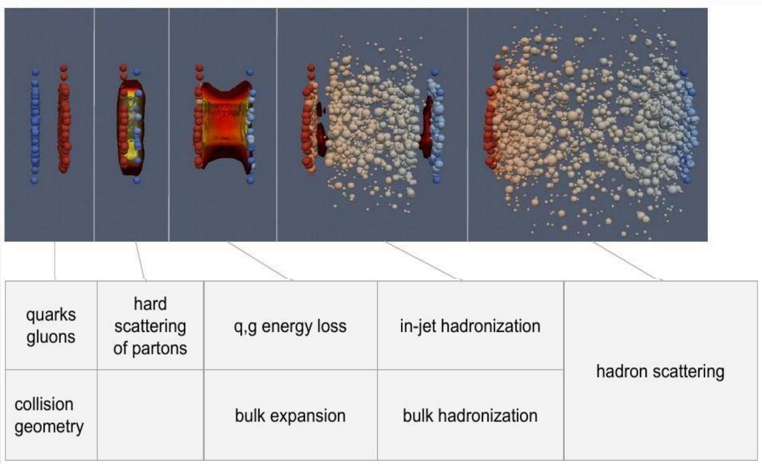
Heavy flavor
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

Discuss physics feasibility studies at regular cross-PWG meetings

Physics feasibility studies

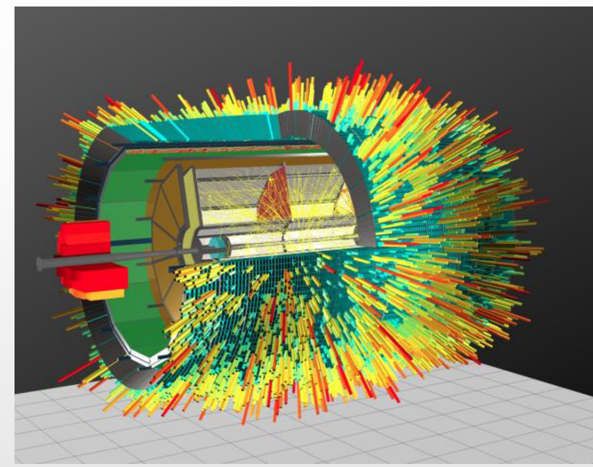
- ❖ Physics feasibility studies using centralized large-scale MC productions
- ❖ Centralized Analysis Framework for access and analysis of data → Analysis Train:
  - ✓ consistent approaches and results across collaboration, easy storage and sharing of codes
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes
- ❖ Mescheryakov Laboratory of Information Technologies takes active participation in MPD collaboration works. We are grateful for provided computing resources, development and support of IT services.

Event generator(s)



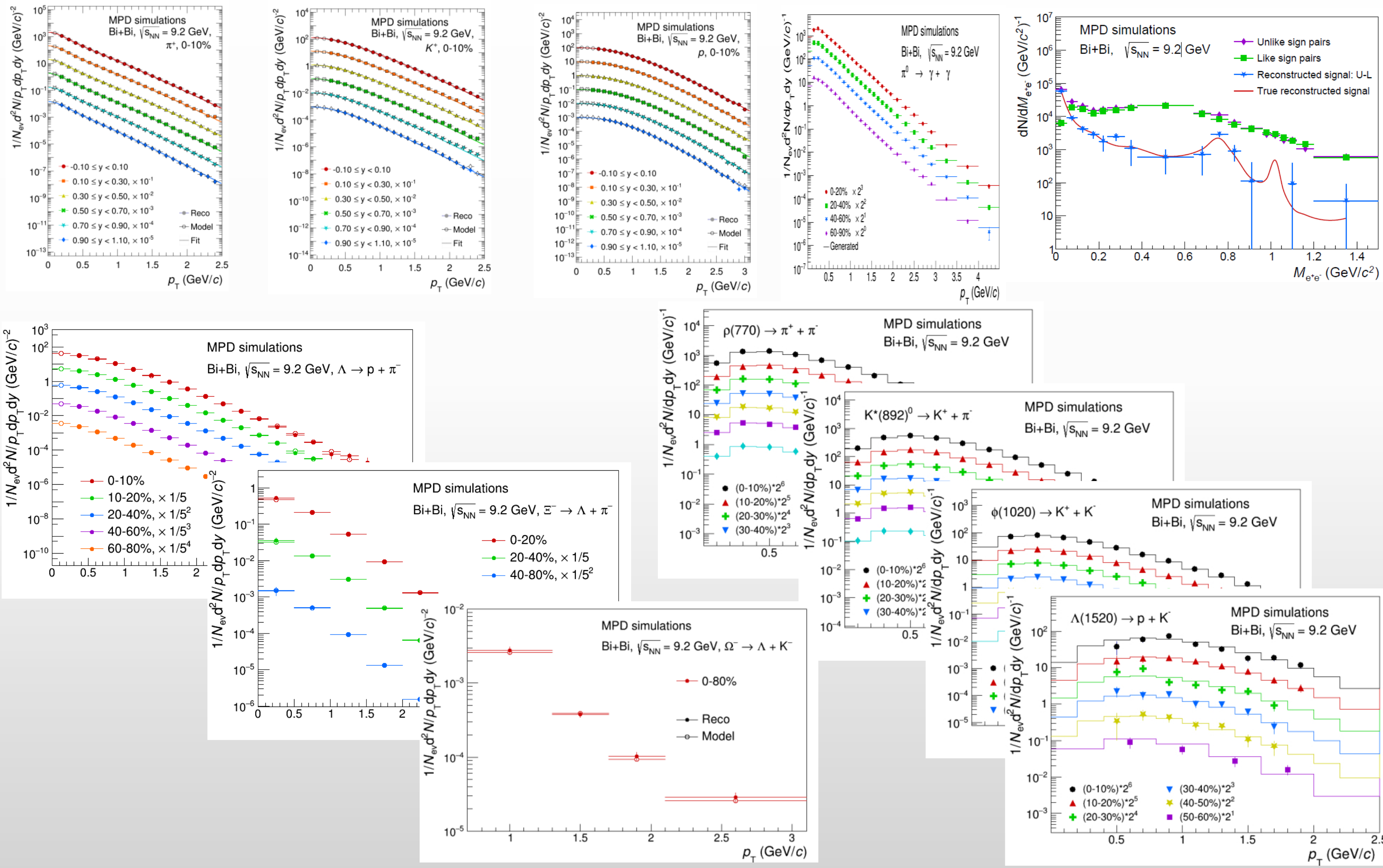
MpdRoot

Particle propagation & detector response



- ❖ Develop physics program, software and analysis infrastructure for real data analysis
- ❖ MPD-CLD and MPD-FXT studies with simulations:
  - ✓ collider mode: Bi+Bi @ 9.2 GeV
  - ✓ fixed-target mode: Xe + W @ T = 2.5 AGeV

❖ Physics feasibility studies using large-scale Monte Carlo productions

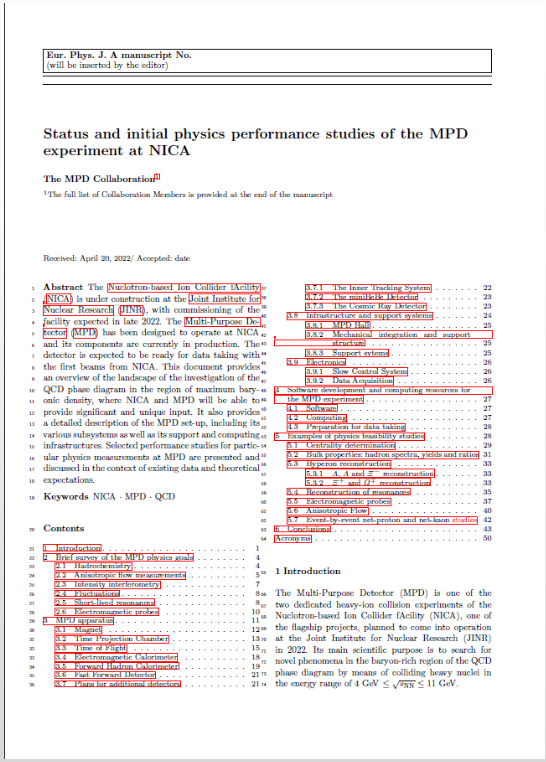


Conference & publication activity

- ~ 50 reports at international conferences per year
- Overall 250+ publications indexed by SPIRES
- 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**
Rev.Mex.Fis. 71 (2025) 4, 041201, e-Print: 2503.21117 (~ 40 pages)



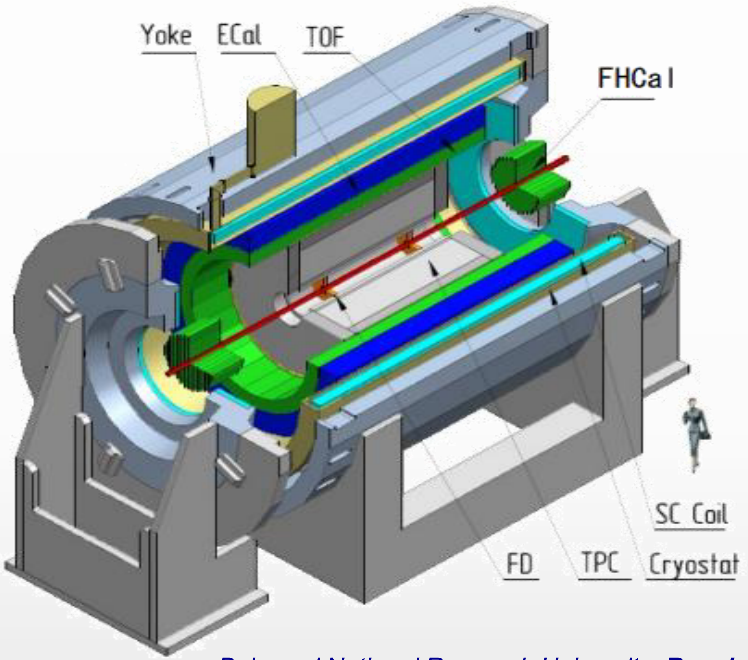
Multi-Purpose Detector (MPD) Collaboration

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

12** Countries, **>500** participants, **38** Institutions 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**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*Institute for Nuclear Problems of Belarusian State University, **Belarus**;*
*Institute of Power Engineering of the National Academy of Sciences of Belarus, **Belarus**;*
*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, Huizhou, **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**;*
*Egyptian Center for Theoretical Physics, **Egypt**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Institute of Physics and Technology, Almaty, **Kazakhstan**;*
*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
*Universidad Autónoma de Sinaloa, **Mexico**;*
*Universidad Autónoma Metropolitana, **Mexico**;*
*Universidad de Colima, **Mexico**;*
*Universidad Michoacana de San Nicolás de Hidalgo, **Mexico**;*
*Institute of Physics and Technology, **Mongolia**;*

*Belgorod National Research University, **Russia**;*
*High School of Economics University, Moscow, **Russia;***
*Institute for Nuclear Research of the RAS, Moscow, **Russia**;*
*National Research Nuclear University MEPhI , Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Ossetian State University, **Russia**;*
*National Research Center "Kurchatov Institute", **Russia**;*
*National Research Tomsk Polytechnic University, **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***

Summary

Collaboration meeting in Dubna, Autumn 2025

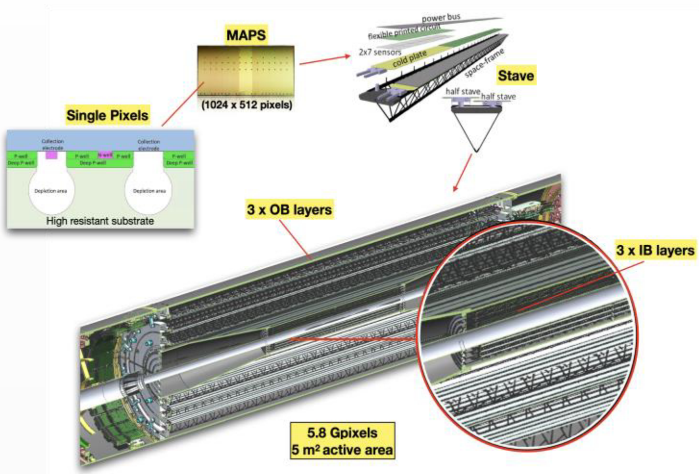
- NICA is progressing, although with noticeable delays
- Flagship project in the world on the study of heavy-ion collisions at intermediate energies
- A comprehensive physics program to be studied for different ions (from p to Au) and collision energies ($\sqrt{s_{NN}}$ from 2.4 to 11 GeV)
- Extensive upgrade program with many uncertainties
- First data taking → end of 2026

For more information please refer to http://mpd.jinr.ru

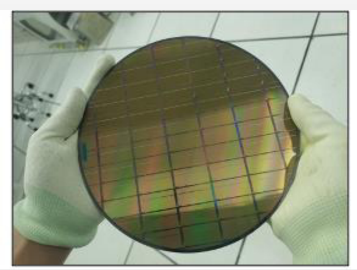

2026

Future upgrade: 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



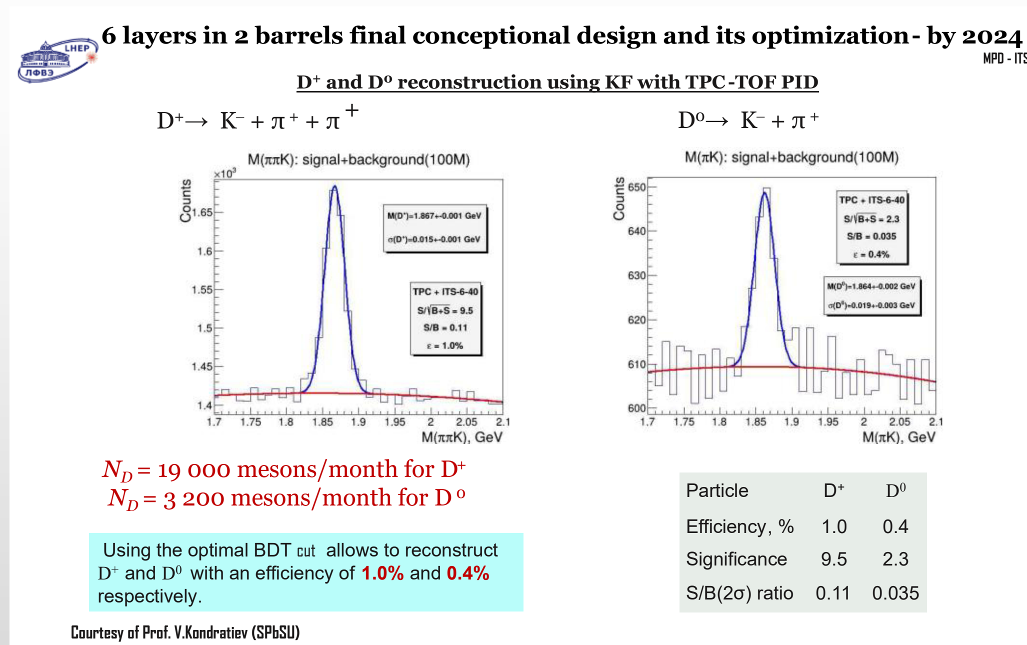
- first prototype of ALPIDE-like MAPS (MICA) sensor developed at CCNU and produced in China

- 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.

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)

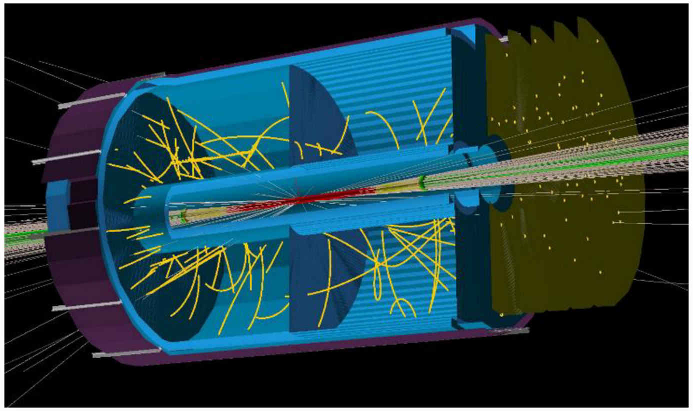
2) An agreement was reached with Chinese partners to jointly research, develop and manufacture in China the missing components needed to build the tracker and its readout system.



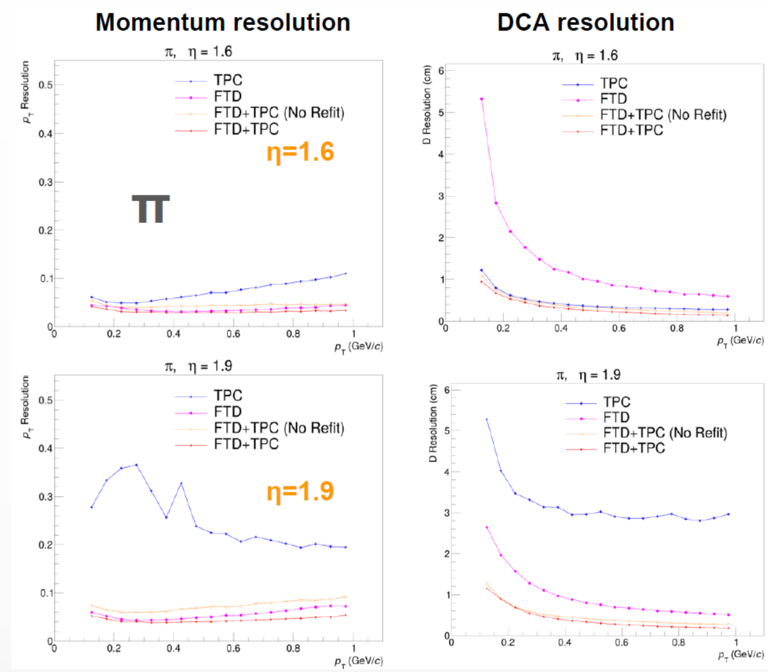
D^0 and D^+ reconstruction using information from ITS+TPC+TOF subsystems

Future upgrade: Forward Spectrometers

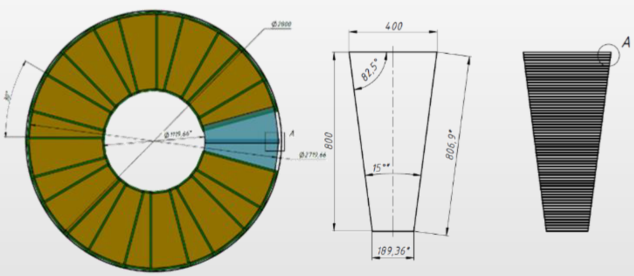
Conception of the Forward Tracker (FTD)



- ✓ five tracking layers within z = 210–300 cm,
- ✓ 1% X_0, ~ 80 μm spatial resolution

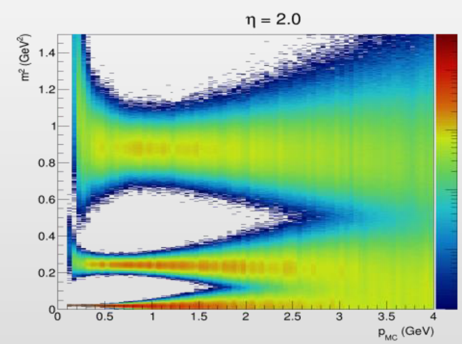


Conception of the end-cup TOF detector



- ✓ 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

π/K/p separation vs. particle momentum



(FTD+TPC) makes possible track reconstruction and identification up to |η| ~ 2 with momentum resolution < 10%