MPD experiment at NICA: status of the project

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VBLHEP, JINR

on behalf of MPD

LXXV International Conference "NUCLEUS-2025"

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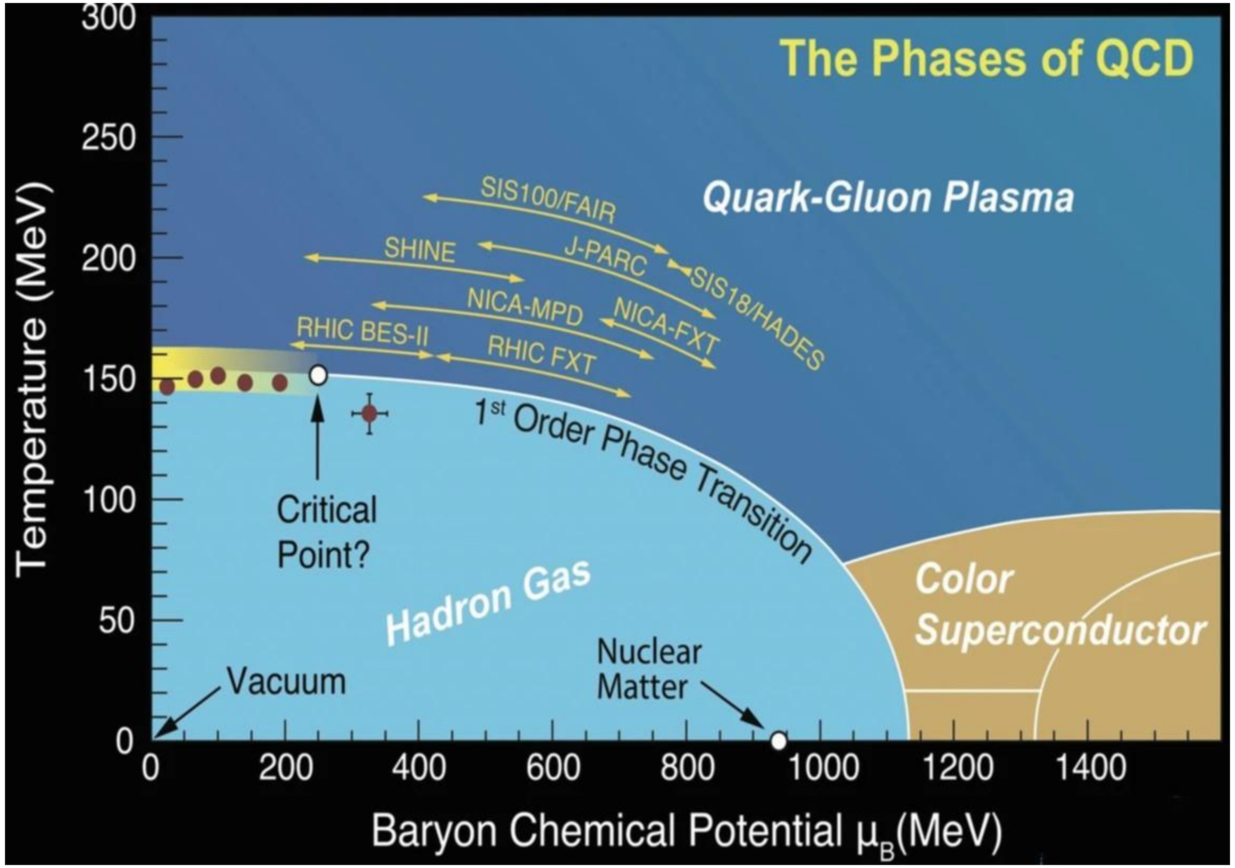
OUTLINE

- Introduction: nuclear matter at NICA energies
- NICA accelerator complex: status and prospects
- MPD detectors for heavy-ion physics at NICA : construction status and preparation for data taking
- Summary

I. Introduction

Heavy-ion collisions and QCD phase diagram



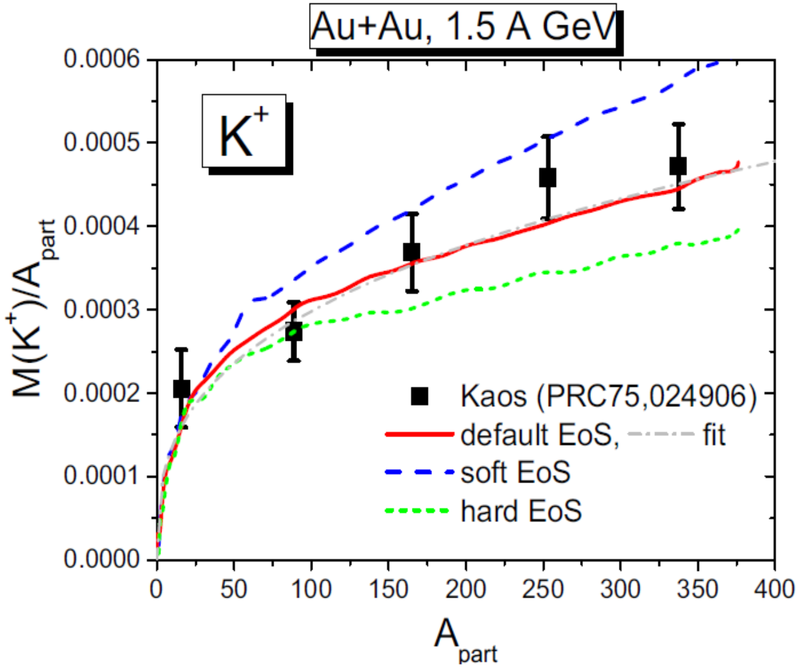
- **QCD phase diagram**: rich structure and variety of conditions. Theoretically probed by lattice QCD and effective models, experimentally by heavy-ion collisions. Location of CEP and 1st order PT is one among major goals

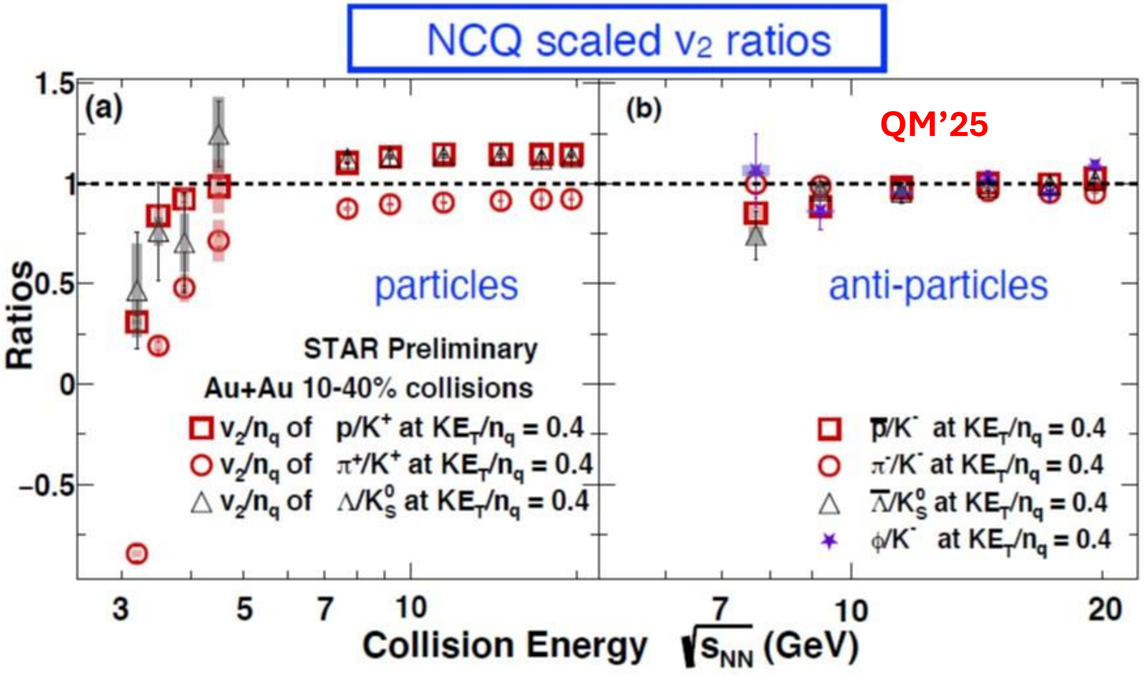
- **High μ_B region**: poorly explored, results from HIC have implications for nuclear physics and astrophysics. Several running and future experimental programs worldwide (RHIC, SPS, **NICA**, HIAF, FAIR)

- ❖ **What is the structure of the QCD phase diagram in the high baryon density region?**
- ❖ **How the dominant degrees of freedom in HIC change with the beam energy and what is the relevant EOS?**
- ❖ **Can the onset of the 1st order phase transition and QCD Critical End Point be detected?**

Nuclear matter in the high-μ_B region: *dof*

- Low energies: baryons and baryon resonances are dominant *dof*, in-medium effects play a role in hadroproduction
- Higher energies: transition from baryon-rich to meson-dominated matter and QGP droplets can be formed
- A gradual onset of NCQ scaling is observed, emergence of partonic collectivity above 7 GeV
- Hadrons provide information about bulk matter properties (dof and EOS), but no consensus about the most compelling signals for the 1st-order phase transition yet (strangeness, flow, dileptons, fluctuations?)!

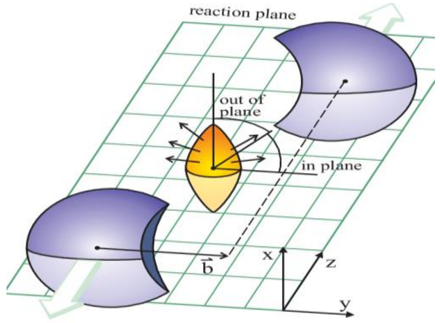




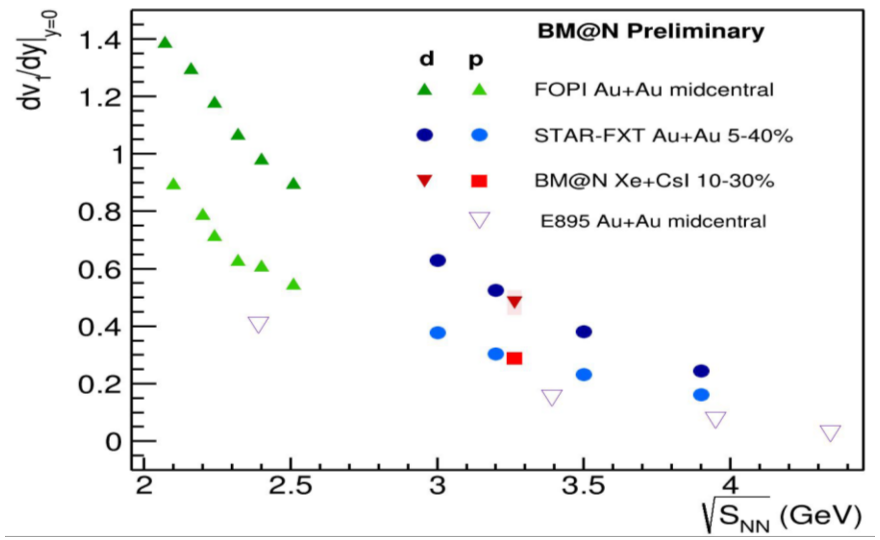
- To probe a possible phase transition, it is necessary to test on a systematic basis as many related observables as possible: excitation function and centrality dependence for <pT>, spectra, yields, flow, correlations.

Nuclear matter in the high-μ_B region: flow and EOS

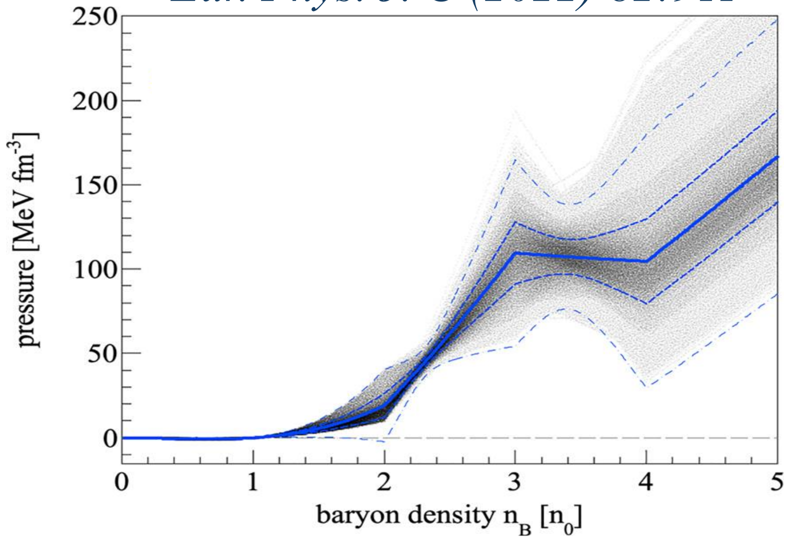
- Angular distributions of produced hadrons are sensitive to the matter compressibility providing access to medium properties (*dof*, viscosity and EOS)



$$\frac{dN}{d\varphi} \approx 1 + 2\sum_{n=1} v_n \cos\left[n\left(\varphi - \Psi_{RP}\right)\right]$$



Eur. Phys. J. C (2022) 82:911



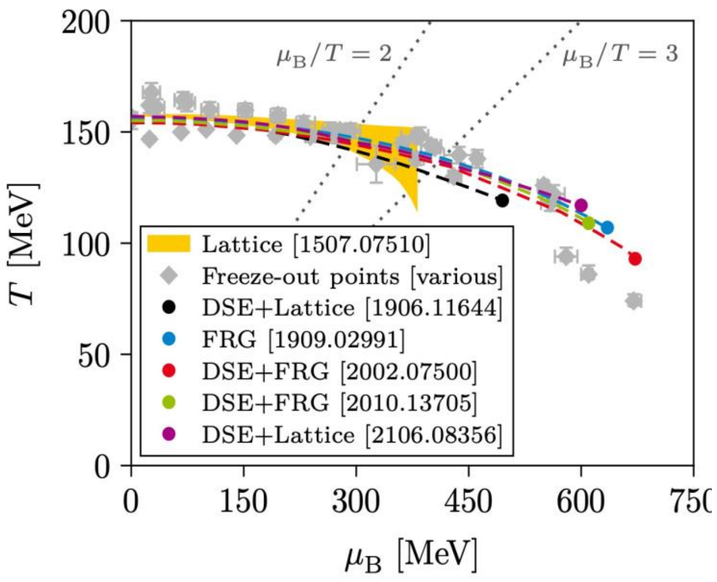
- Recent STAR flow data (supported by BM@N measurements) favors a stiff EOS up to (2-3)n_0 followed by softening at higher densities (1st-order PT?). It contradicts old AGS/E895 data and disfavors a large EOS softening based on NS data (isospin asymmetry plays a role!)

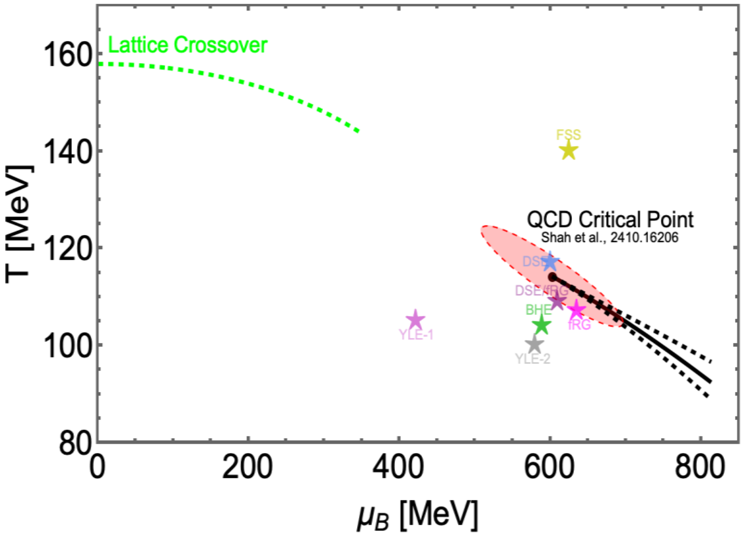
- Precise measurements of differential flow observables will be necessary to provide better global constraints to the EOS in the high baryon density domain and to QCD matter transport properties
- A variety of nuclei of different sizes and isospin content should be studied
- Dependence on pT , rapidity, and particle species can provide stringent constraints to models

Nuclear matter in the high-μ_B region: CEP

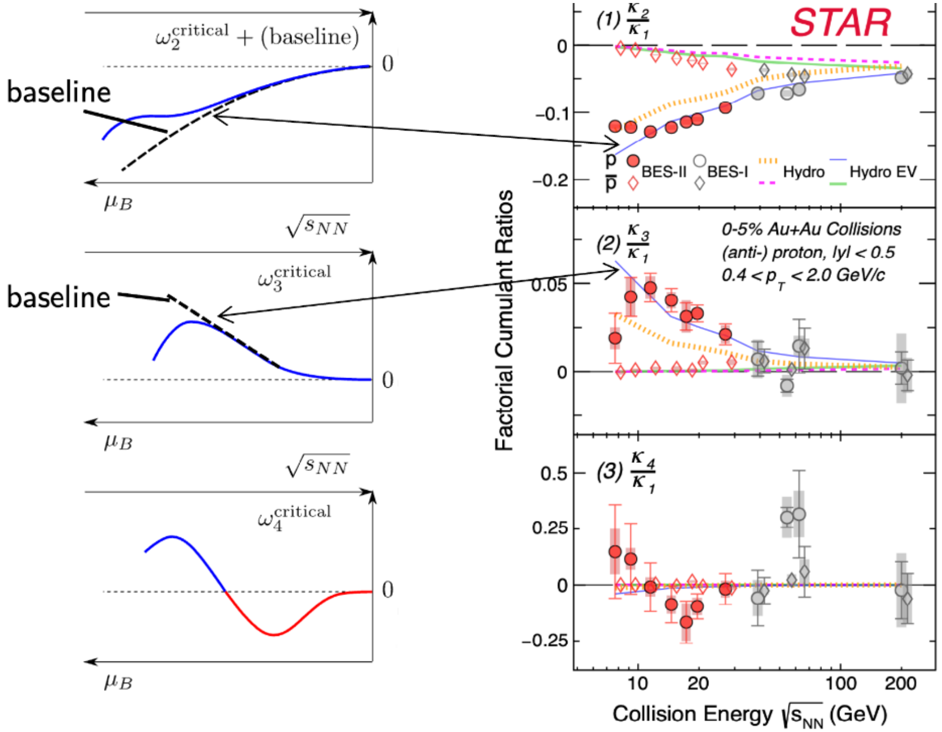
- Recent LQCD results indicate that T_{crit} < 135 MeV and a HG←→QGP transition is a crossover at $\mu_B/T < 3$
- Combining different theory approaches, CEP location might be in the region of T and μ_B that are achievable by the NICA experiments (μ_c, T_c) = (495 - 654, 100 - 119) MeV
- BES-II results: max. deviation from a "non-critical baseline" is within $3 < \sqrt{s} < 20$ GeV

PRD 105: 074511 (2022); PRL 123: 062002 (2019); PLB 820: 136584 (2021);





M. Stephanov, arXiv:2410.02861

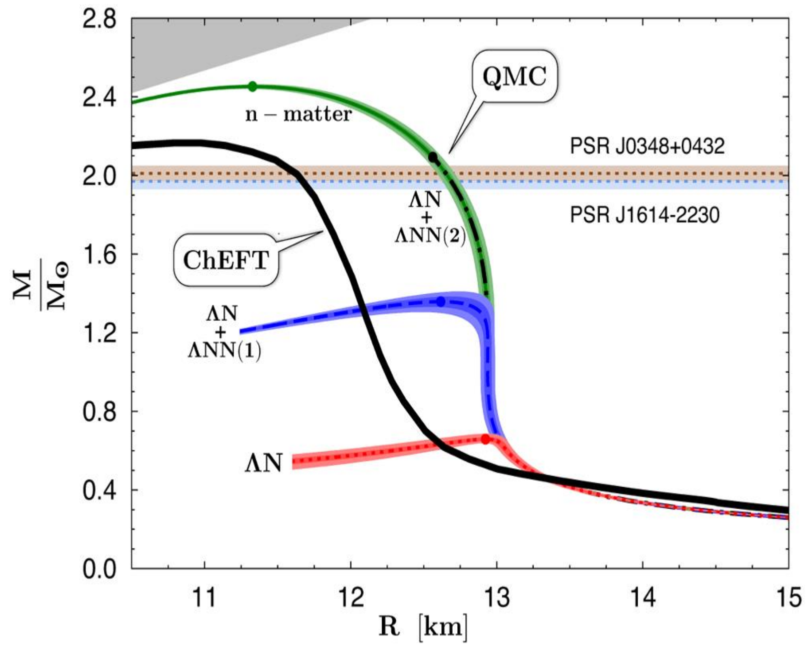


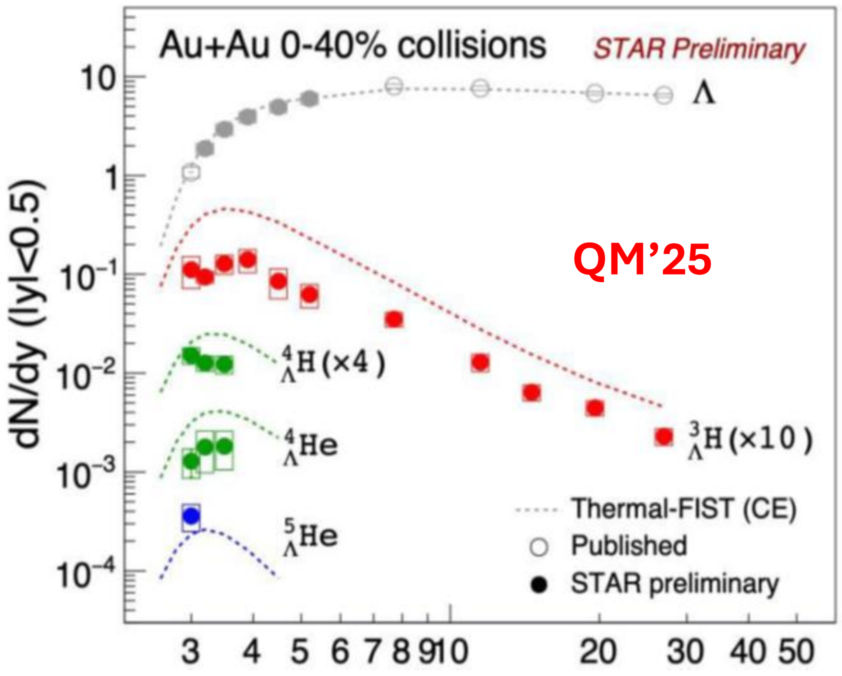
- Ratios of cumulants of conserved quantities are suggested to be sensitive to CEP
- Experimental strategy: vary collision energy and system size to probe different trajectory across phase diagram and to observe a non-monotonic behavior of fluctuation measures

Nuclear matter in the high-μ_B region: hypernuclei

- YN and YY potential are crucial for the nuclear matter EOS at high density (nuclear physics and astrophysics)
- Hyperon *dof* makes EoS for neutron stars softer and the max NS radius smaller → **in contradiction with observations**
- Max. production rates of (hyper)nuclei at 3-5 GeV → **optimal to test YN interactions**
- Models reproduce the trend, but overestimate the yields of hypernuclei → **challenge for models**

REVIEWS OF MODERN PHYSICS 88 (2016)





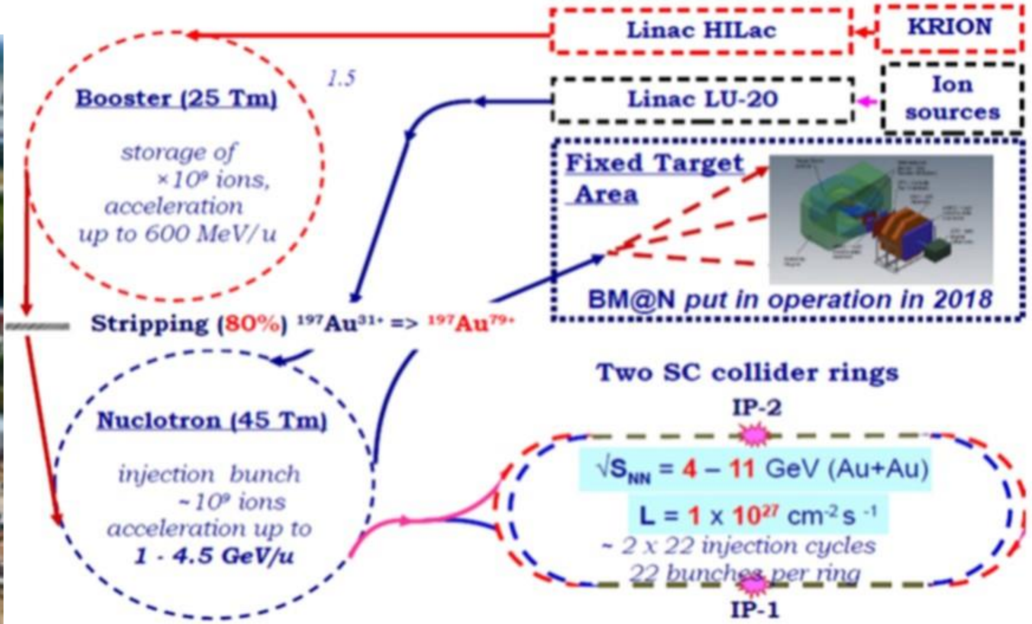
QM'25

- New data from NICA on hypernuclei yields, binding energies, lifetimes, branching ratios are needed to provide tighter constrains to the strange sector of the nuclear matter EOS and input for theoretical developments in the formation of loosely bound objects in heavy-ion collisions

II. NICA complex : status

NICA – Nuclotron-based Ion Collider fAcility (JINR, Dubna)

- A chain of accelerators providing ion beams for fundamental physics studies & applied research
- Modern detectors for study dense nuclear matter and spin phenomena (MPD, SPD, BM@N)
- Experimental zone with beam lines for fundamental and applied research

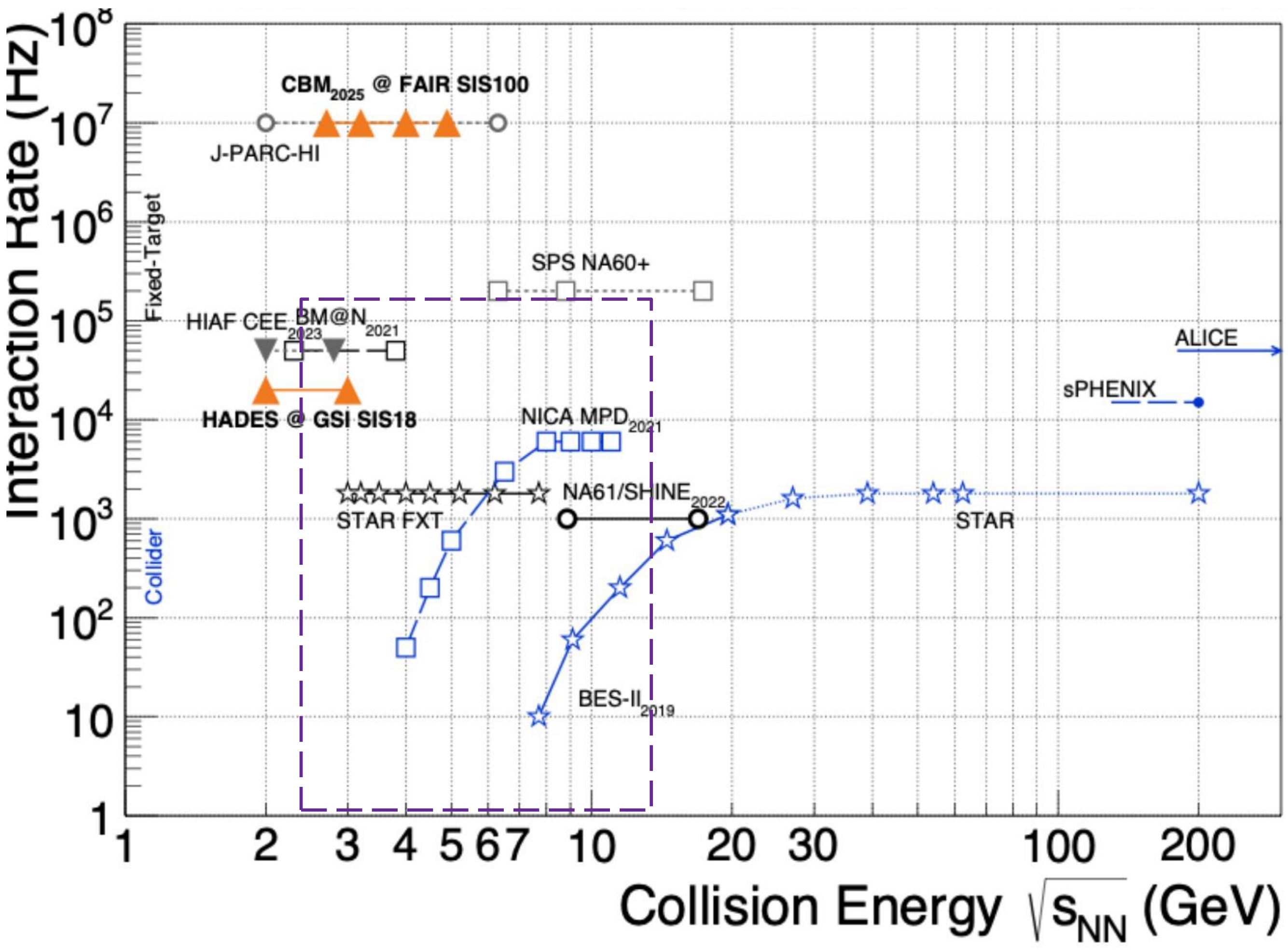


Z/A	$\sqrt{s}$ (GeV)	L (cm^{-2} c^{-2})
1 (protons)	27	10^{32}
0.5 (light nuclei)	13	10^{28}
~0.4 (heavy nuclei)	11	10^{27}

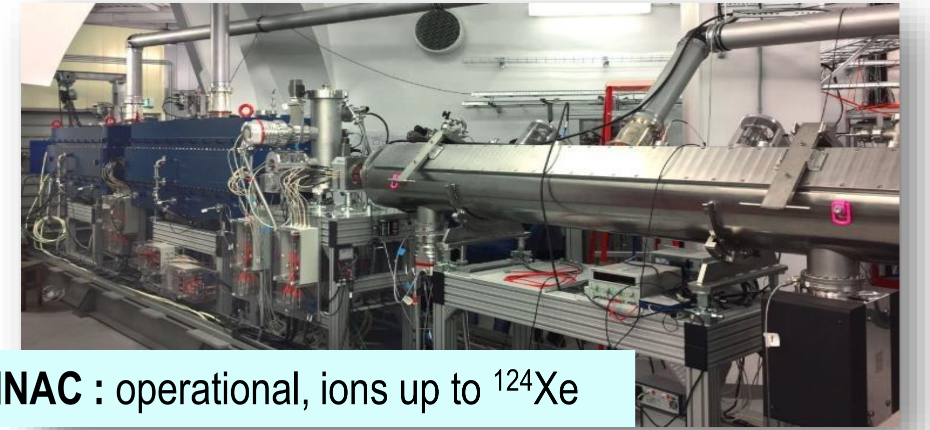
Beam species at NICA and event rates

- Many beam combinations at NICA, a beam energy and system-size scan will be performed
- A high event rate in the region of the max. baryonic density: up to 7 kHz for Au+Au collisions

Beam	Beam intensity (particle / cycle)		
	Current	Ion source type	at NICA
p	$3 \cdot 10^{10}$	Duoplasmotron	$5 \cdot 10^{12}$
d	$3 \cdot 10^{10}$	--- „ ---	$5 \cdot 10^{12}$
^{4}He	$8 \cdot 10^{8}$	--- „ ---	$1 \cdot 10^{12}$
d↑	$2 \cdot 10^{8}$	SPI	$1 \cdot 10^{10}$
^{7}Li	$8 \cdot 10^{8}$	Laser	$5 \cdot 10^{11}$
^{11,10}B	$1 \cdot 10^{8}$	--- „ ---	
^{12}C	$1 \cdot 10^{9}$	--- „ ---	$2 \cdot 10^{11}$
^{24}Mg	$2 \cdot 10^{7}$	--- „ ---	
^{14}N	$1 \cdot 10^{7}$	ESIS (“Krion-6T”)	$5 \cdot 10^{10}$
^{40}Ar	$1 \cdot 10^{9}$	--- „ ---	$2 \cdot 10^{11}$
^{56}Fe	$2 \cdot 10^{6}$	--- „ ---	$5 \cdot 10^{10}$
^{84}Kr	$1 \cdot 10^{4}$	--- „ ---	$1 \cdot 10^{9}$
^{124}Xe	$1 \cdot 10^{4}$	--- „ ---	$1 \cdot 10^{9}$
^{197}Au	-	--- „ ---	$1 \cdot 10^{9}$
^{209}Bi	-	--.--	--



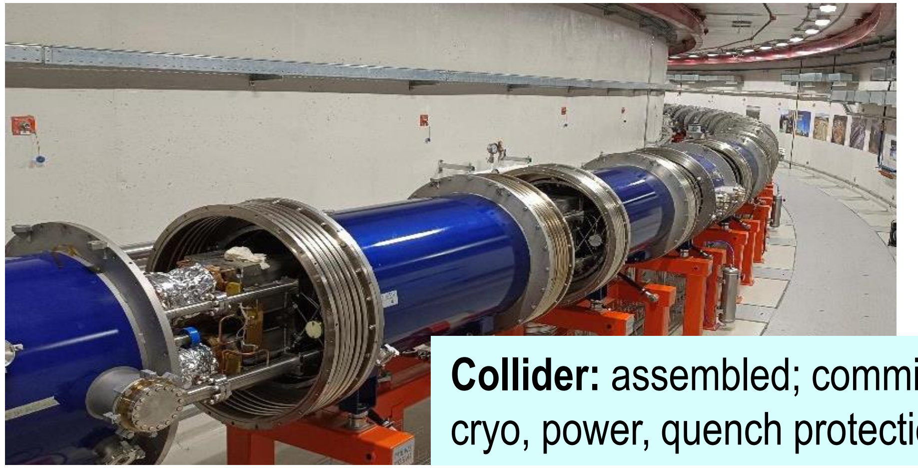
NICA : status of the accelerator complex



HILINAC : operational, ions up to ^{124}Xe

Booster : operational, beams up to Xe E/A~600 MeV

NUCLOTRON: operational, beams up to Xe, E/A = 0.5-4.5 GeV



Collider: assembled; commissioning; vacuum, cryo, power, quench protection tests

- NICA is approaching full commissioning, all infrastructure elements are ready (cryo, electricity, water, etc.)
- Fixed target mode is fully functional, ion beams up to to ^{124}Xe (E/A=0.5-4.5 GeV) are provided by Nuclotron,
- The (fixed-targed) BM@N experiment has taking data (collisions with C, Ar and Xe beams are recorded)
- Collider and MPD detector commissioning : 2025 onwards

III. MPD experiment @ NICA : progress

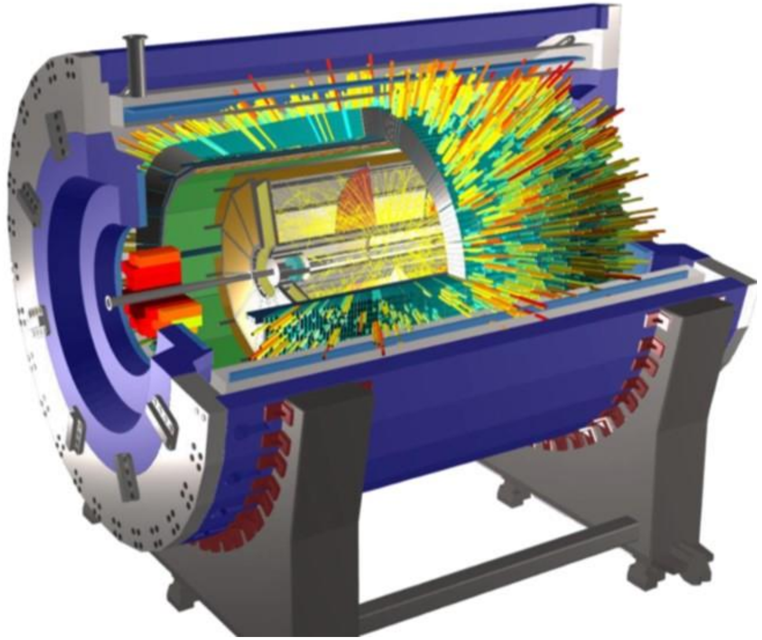
Multi-**P**urpose **D**etector (MPD) Collaboration

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**;*
*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***

MPD physics program

***Experimental strategy*: energy and system size scan to measure a large variety of signals systematically changing collision parameters (energy, centrality, system size). Uniform acceptance of the setup is an advantage.**

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https://doi.org/10.1140/epja/s10050-022-00750-6
THE EUROPEAN PHYSICAL JOURNAL A

Review

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

The MPD Collaboration

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Communicated by N. Alamanos.

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.

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 projects, planned to come into operation at the tute for Nuclear Research (JINR) in 2022. I entific purpose is to search for novel phenor baryon-rich region of the QCD phase diagrar

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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. Kireyeu, 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

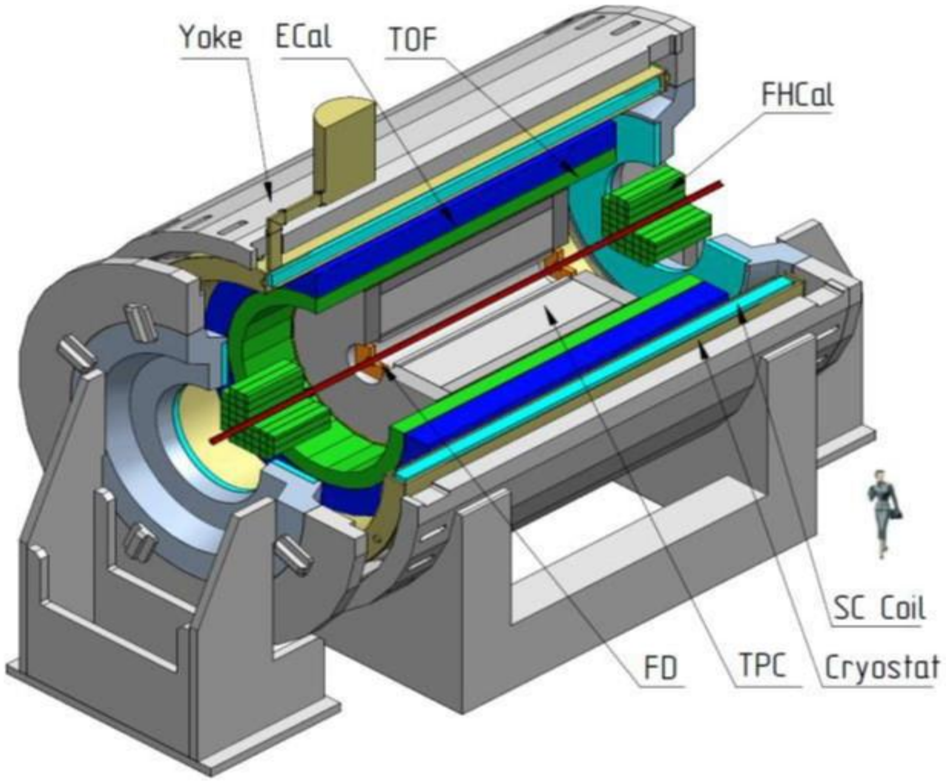
Wangmei Zha, A. Zinchenko

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

- Detailed detector feasibility studies using large-scale Monte Carlo samples
- Centralized MPD Analysis Framework for data access & analysis

Multi-Purpose Detector



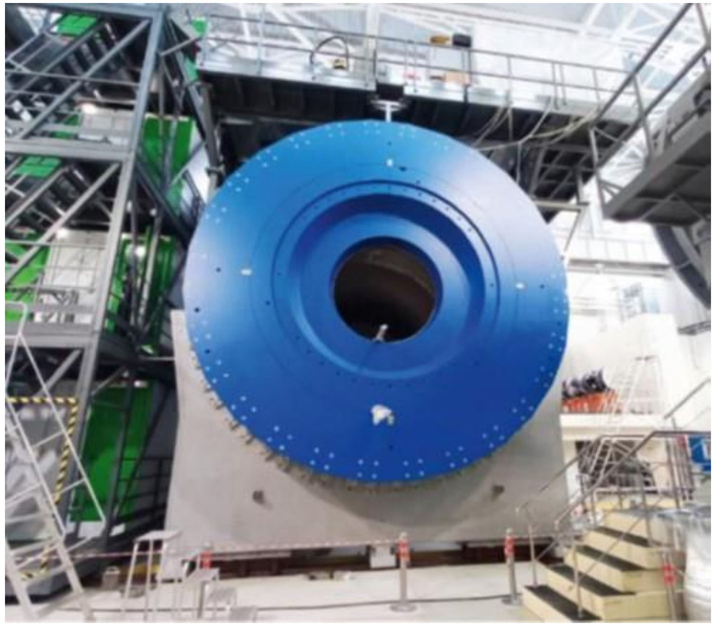
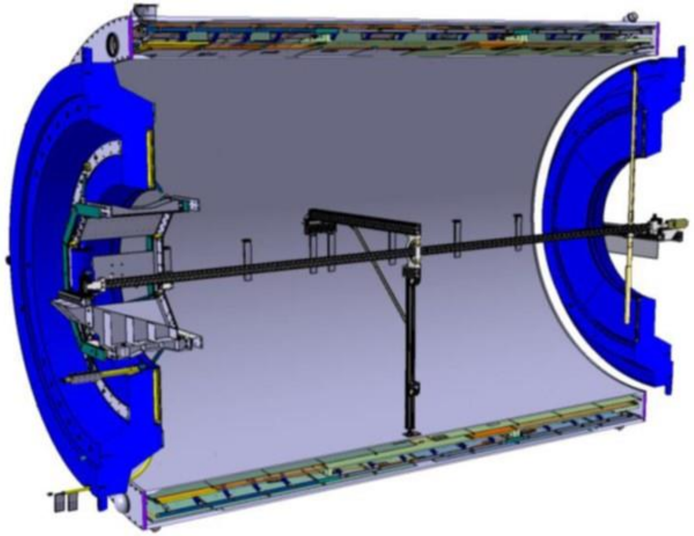
- Uniform acceptance
- 3D tracking, combined PID (dE/dx + TOF and ECAL for e/γ)
- Precise event characterization and event plane (FHCAL)
- Fast timing and triggering (FFD)
- Upgrades (>2028) with central and endcap tracker + PID at $|\eta|>1.6$)

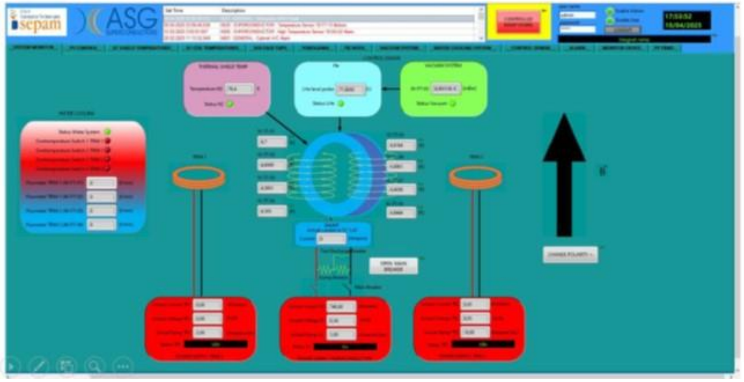
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$
TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

Fully assembled detector - by the end of 2025, commissioning with beams in 2026

MPD magnet: status

- MPD superconducting solenoid houses all detector elements
- Magnet + 2 correction coils will provide magnetic field up to 0.5 T, $\Delta B/B \sim 10^{-4}$



MPD Magnet:

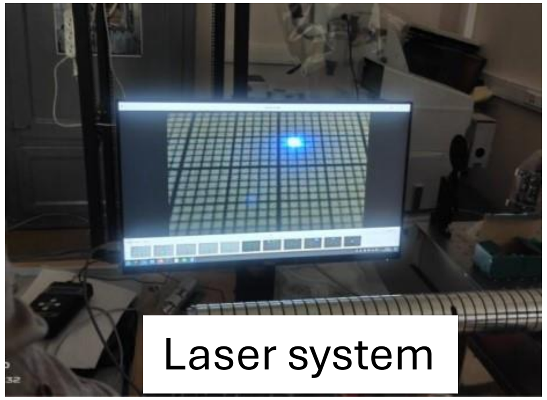
- Successfully cooled to working temperature of 4.2 K
- Test current supply up to 0.2 T
- Magnetic field measurements with a dedicated mapper (Novosibirsk) start in June

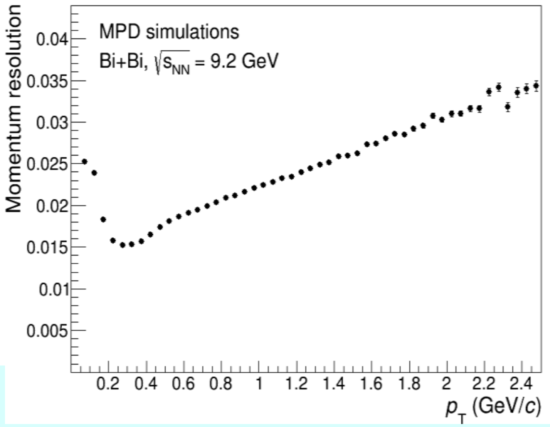
MPD TPC: status

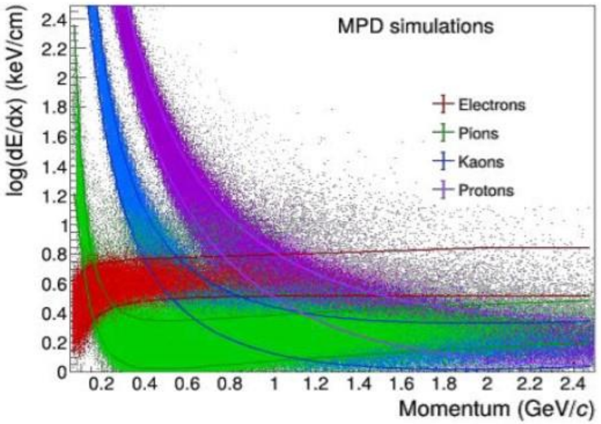
- MPD Time-Projection Chamber – main tracking device (phase-space coverage over $|\eta| < 1.5$ with full azimuth) providing particle ID with dE/dx measurements


Pad calibration


Gas supply


Laser system



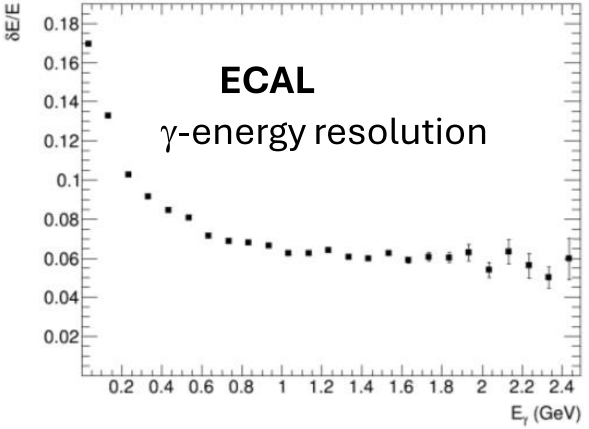


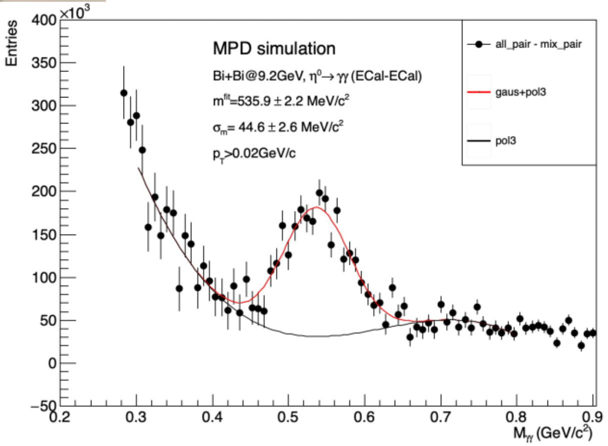
MPD TPC:
- All elements and subsystems are constructed and tested
- Full TPC assembling and final tests start this summer following integration to MPD

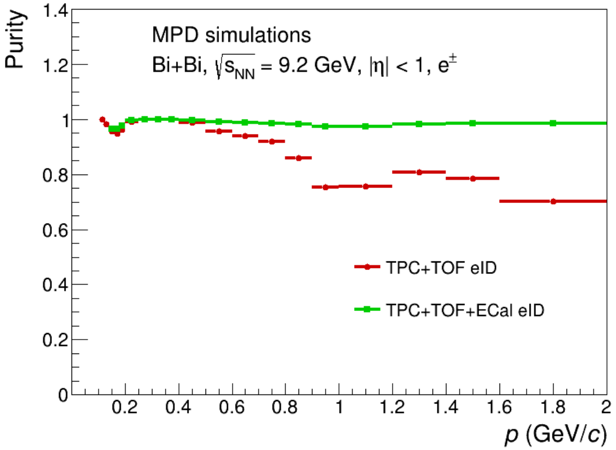
MPD PID detectors (TOF and ECAL): status

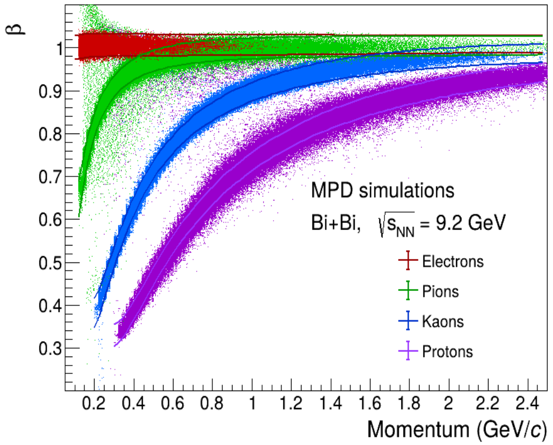
- MPD Time-Of-Flight system – MRPC chambers providing hadron ID, σ_{TOF} ~ 80 ps
- MPD ECAL for e/γ measurements











ECAL: modules will be installed in 2025

Talk of Y.Wang on Tue. 01/07 at 18:40

Talk of S.Rode on Thu. 03/07 at 17:40

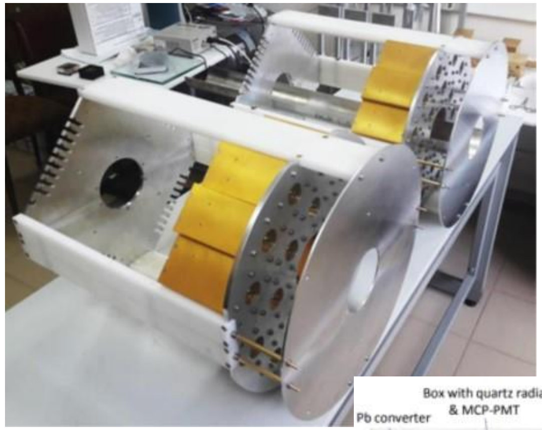
TOF: All MRPC modules are ready and under tests

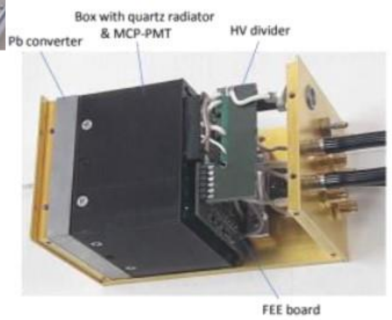
Talk of V.Babkin on Sat. 05/07 at 15:10

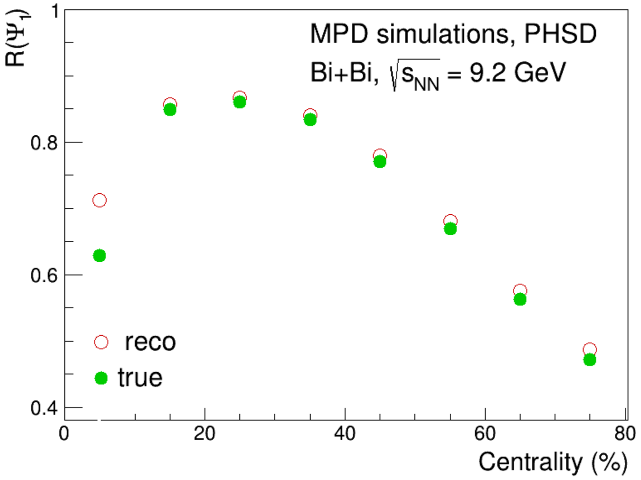
MPD forward detectors (FHCAL and FFD): status

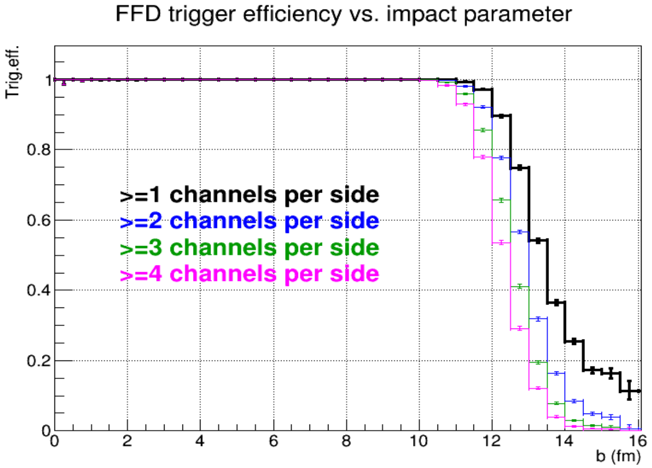
- MPD **F**orward **H**adron **Cal**orimeter – to detect spectators and define centrality & event plane
- MPD **F**ast **F**orward **D**etector - arrays of Cherenkov detectors for triggering and timing

FHCAL









- FHCAL has assembled on its platform, test installation in the magnet pole
- FFD is ready, long-term tests with cosmic rays & laser ongoing
- Final full installation FFD+FHCAL - fall 2024

MPD : status of infrastructure and assembling tooling

- Cryogenics, cabling, piping, cooling, electronics etc.
- Tooling for installation of MPD subsystems

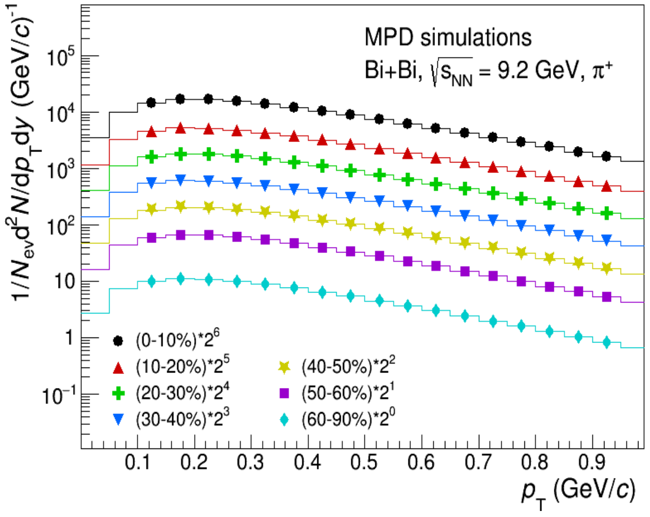
Fiber support frame

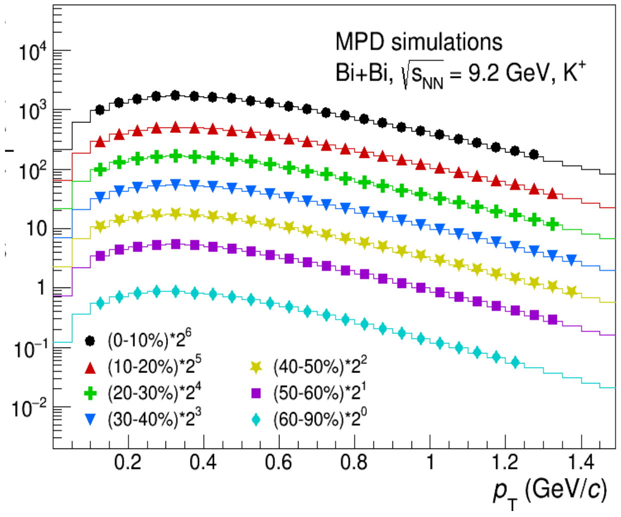
TOF installation bench

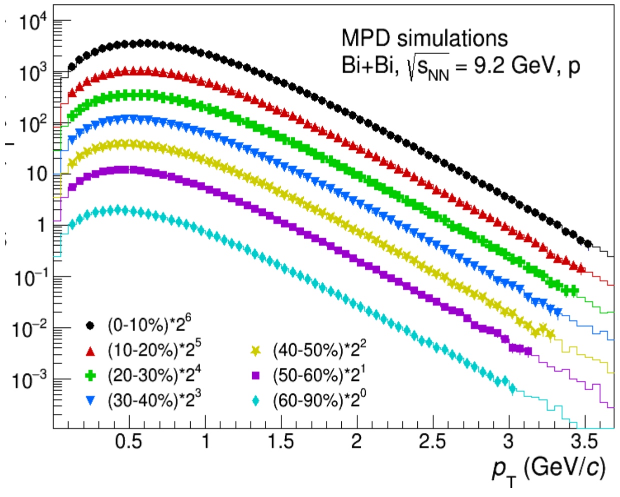
MPD feasibility study: light identified hadrons

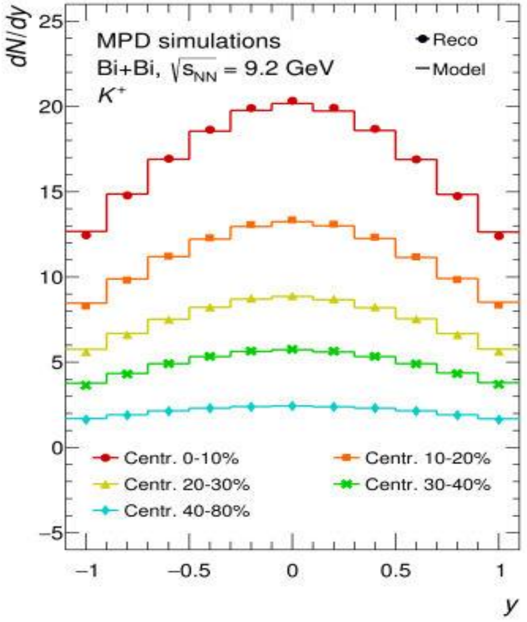
- Bi+Bi at 9 GeV: MPD will be able to measure differential spectra, yields and ratios for a variety of hadrons

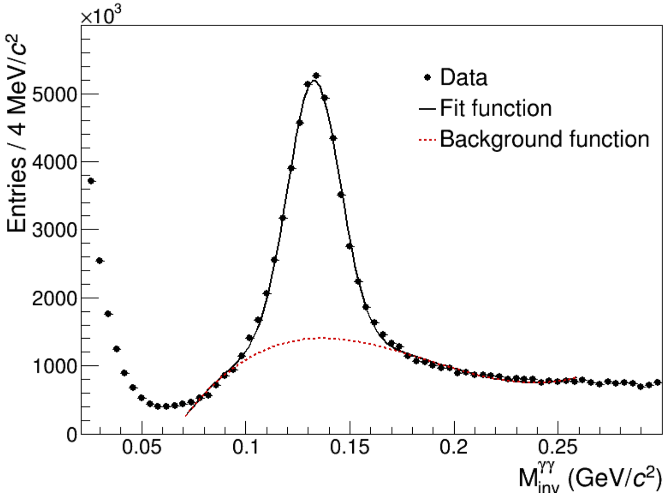
Eur. Phys. J. A 58 (2022) 7, 140; nucl-ex>arXiv:2503.21117

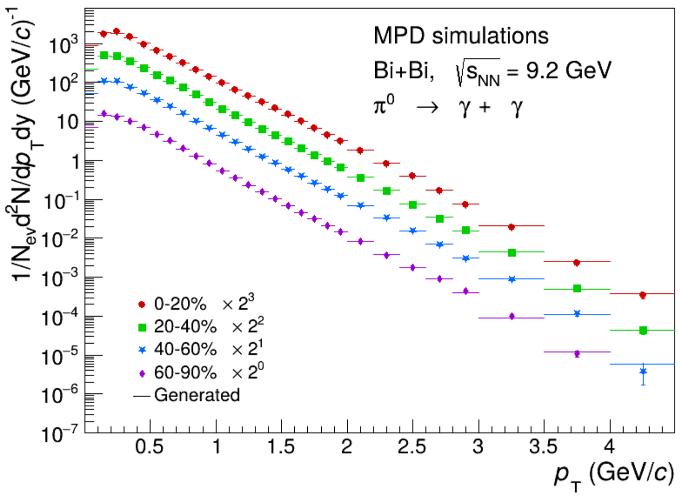










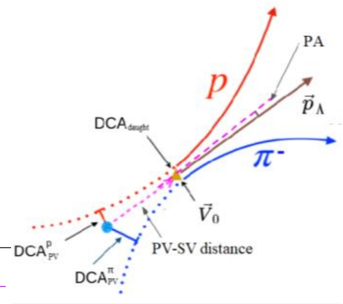


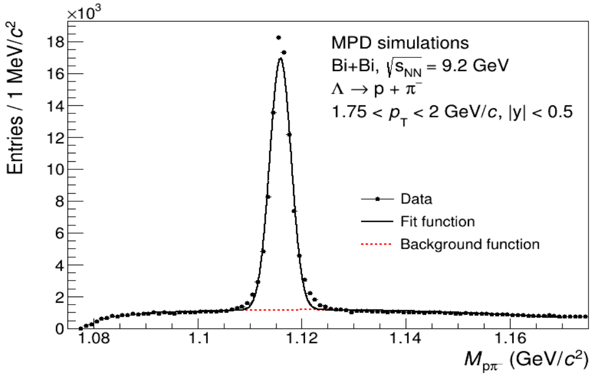
- Charged hadrons: excellent PID and good phase-space coverage (~ 70% of the π/K/p)
- Neutral mesons (π^0, η, K_S, ω, η'): ECAL reconstruction + photon conversion method (PCM) allow to extend p_T ranges of charged particle measurements and provide different systematics

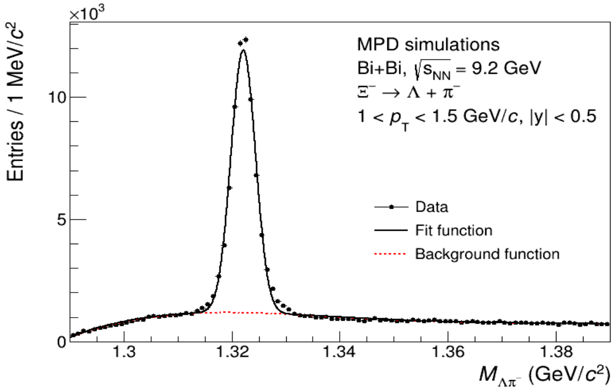
Talk of O.Golosov on Sat. 05/07 at 14:10

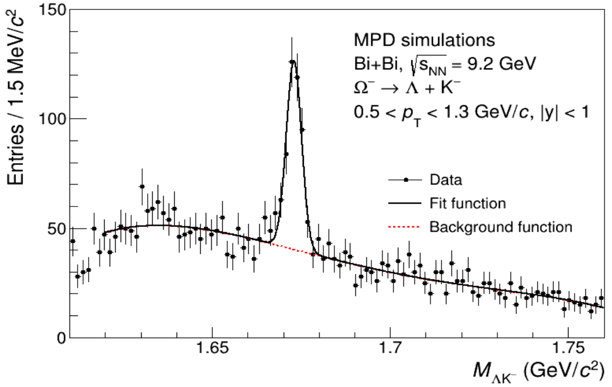
MPD feasibility study: (multi)strange baryons

- Secondary vertex reconstruction (topology selections) in the TPC and PID for daughters









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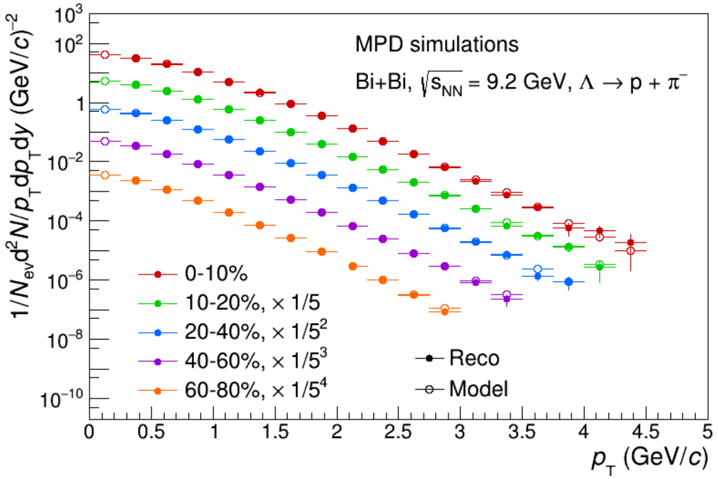
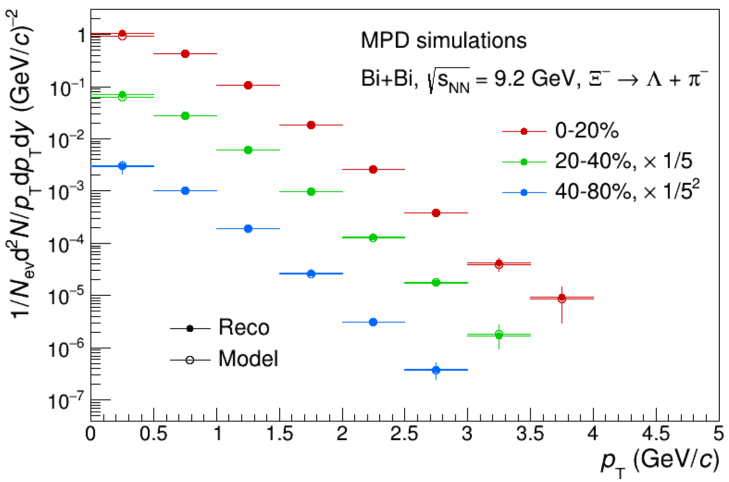
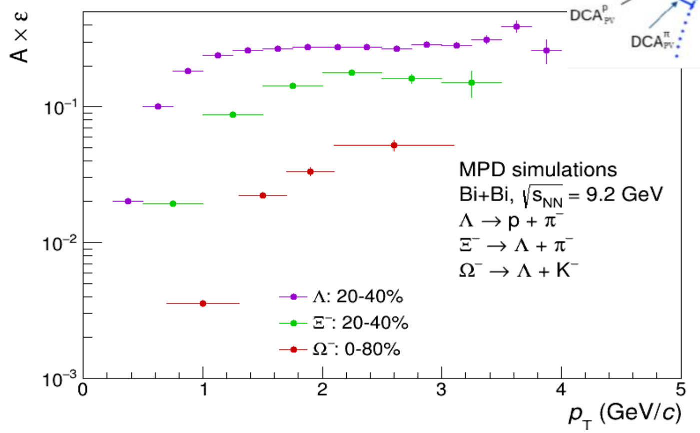
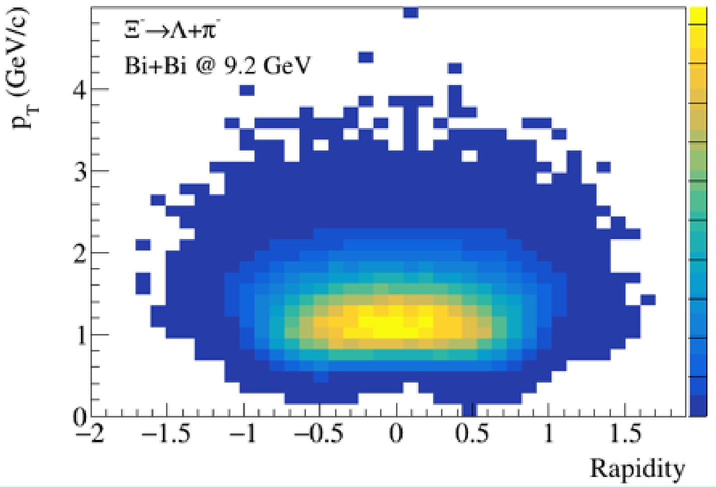
nucl-ex>arXiv:2503.21117







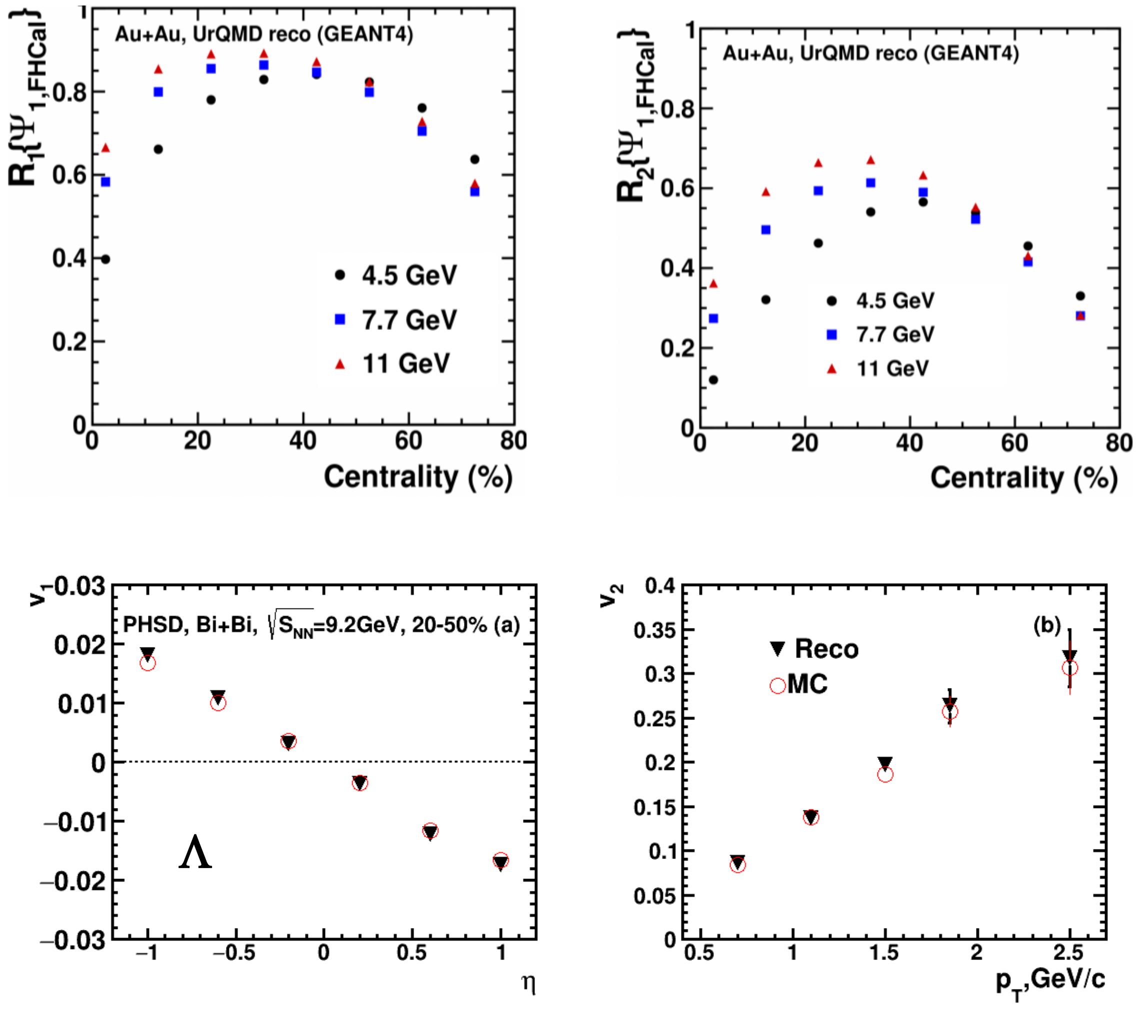


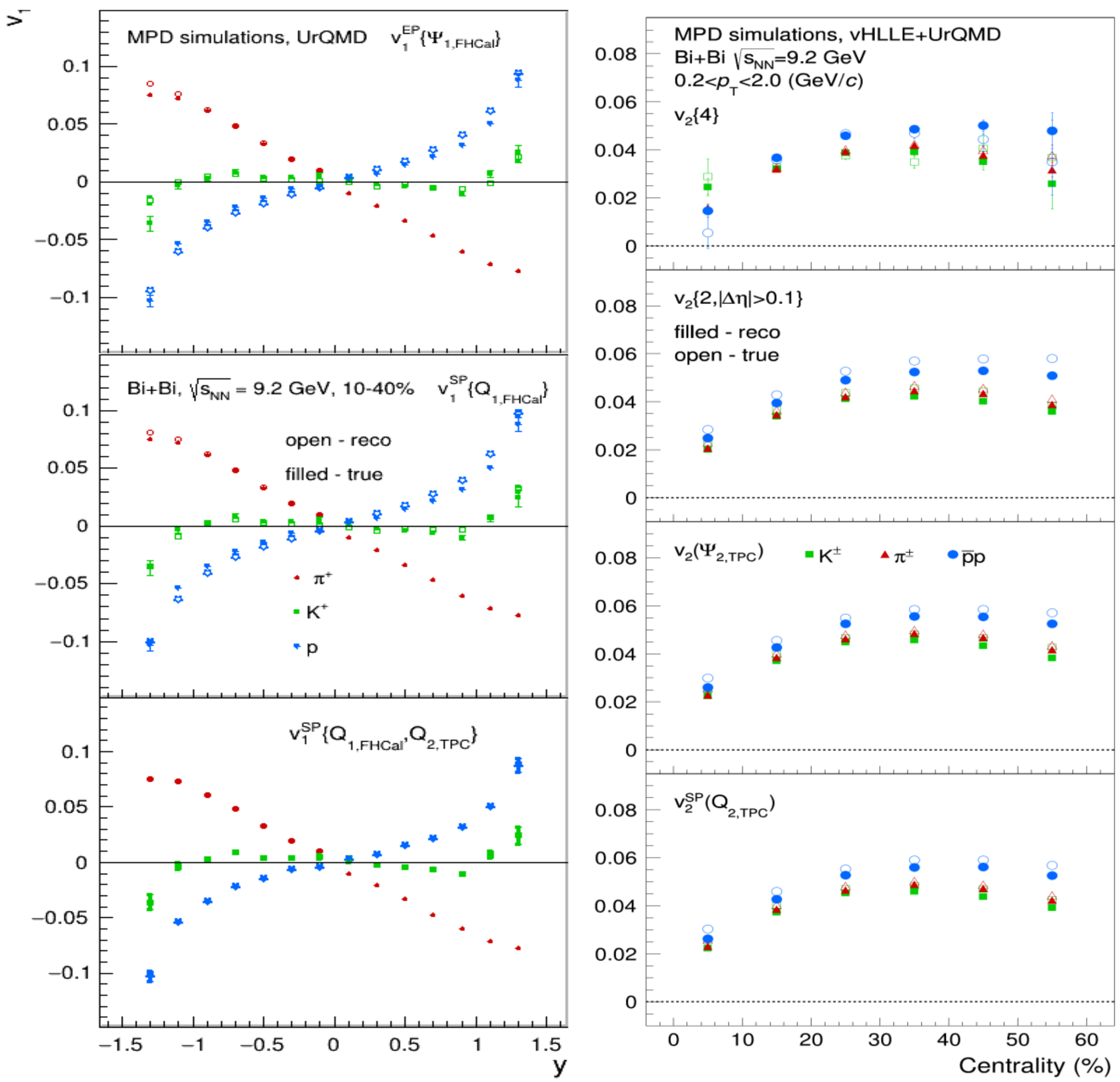
MPD setup performance for hyperons:
- large signal-to-background ratios
- good phase-space coverage

MPD feasibility study: flow

- BiBi@9.2 GeV (UrQMD) : full detector simulation and reconstruction
- MPD has good capabilities for differentia measurements of anisotropic flow for identified hadrons and hyperons

nucl-ex>arXiv:2503.21117

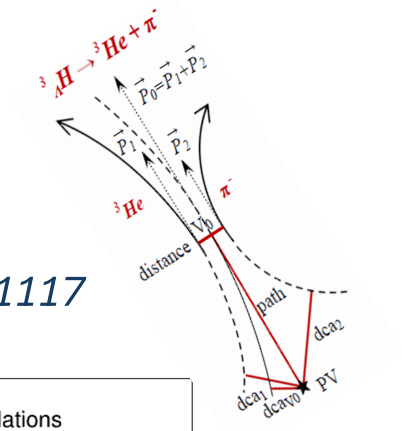




Talk of A.Taranenko on Sat. 05/07 at 16:50

MPD feasibility study: hypertritons

- Charged particle tracking and excellent particle identification capabilities allow reconstruction of hypernuclei



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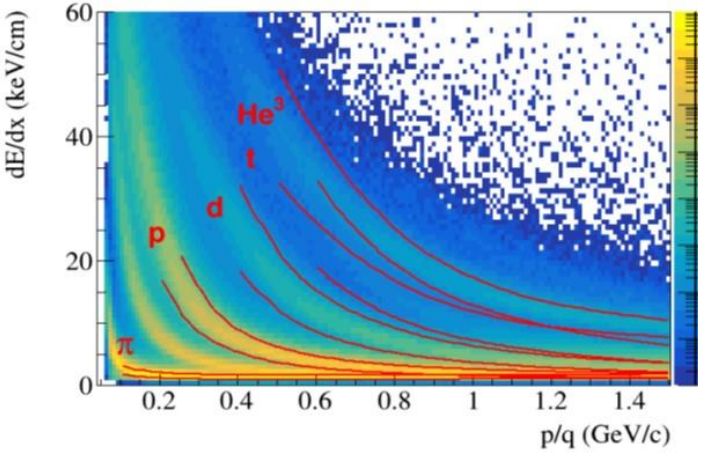
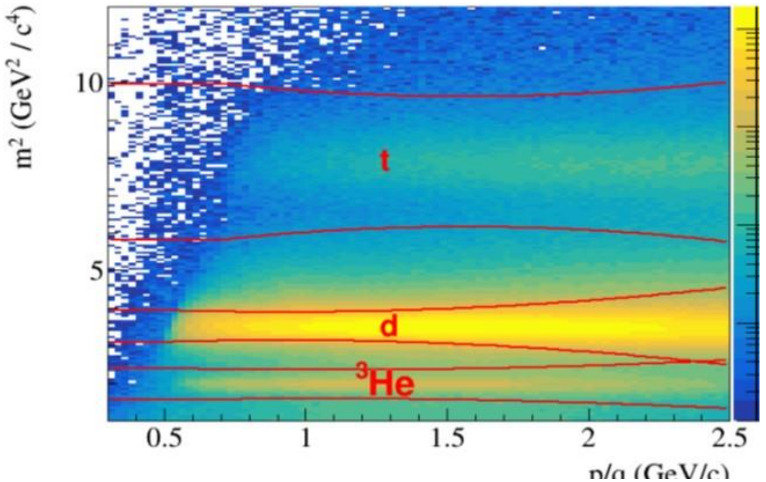
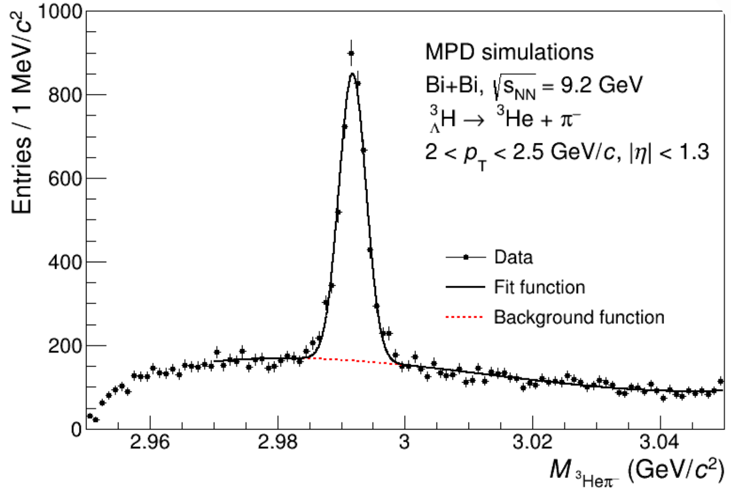
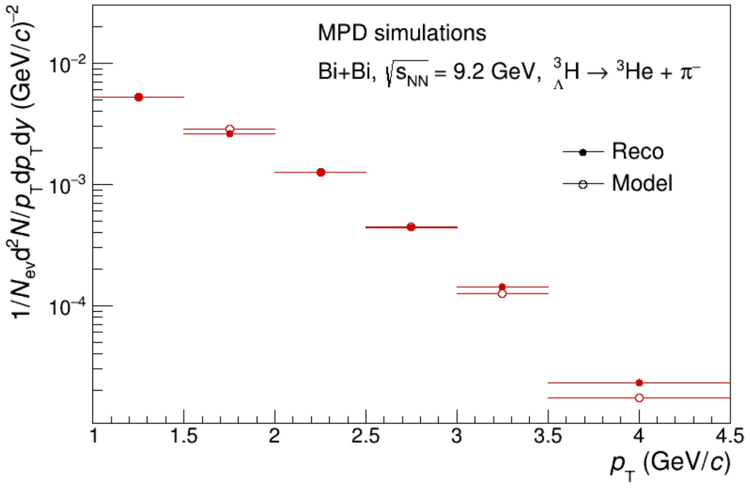
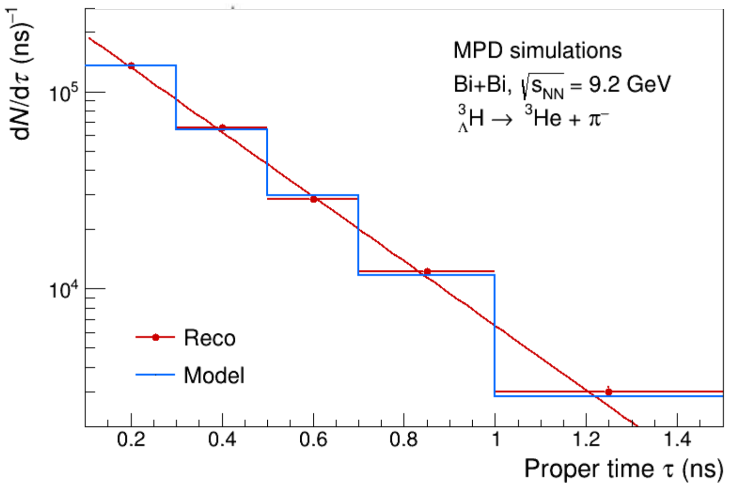






$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right),$$





- Future high-statistics runs from NICA/MPD will provide measurements of several hypernuclear species to better constrain hypernuclei production models in the high baryon density regime

MPD feasibility study: event-by-event fluctuations

- Moments of eve-by-eve multiplicity distributions of conserved charges (net-baryon, net-strangeness, net-charge) are sensitive to critical phenomena.

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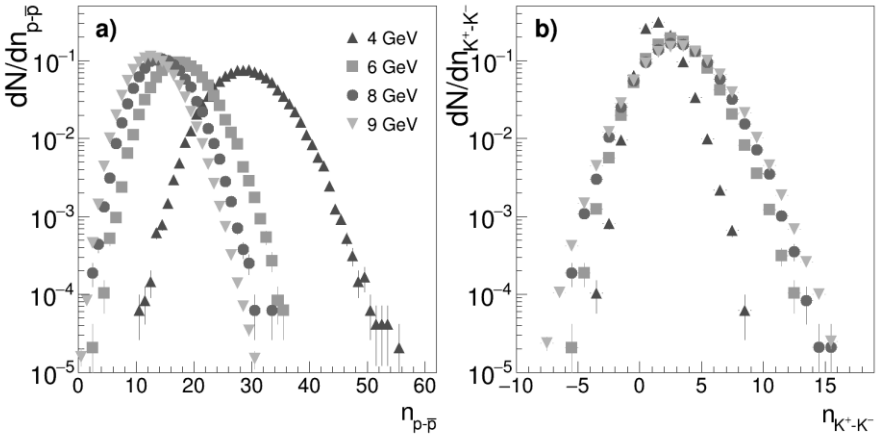
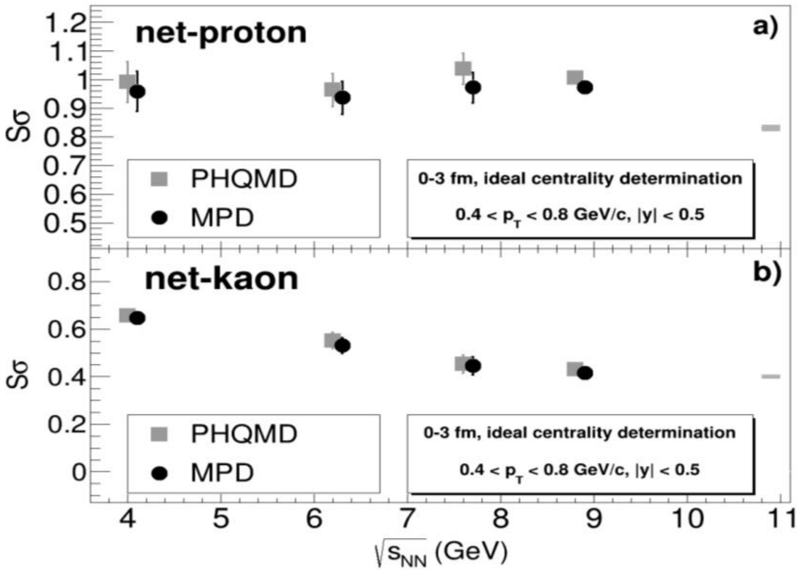
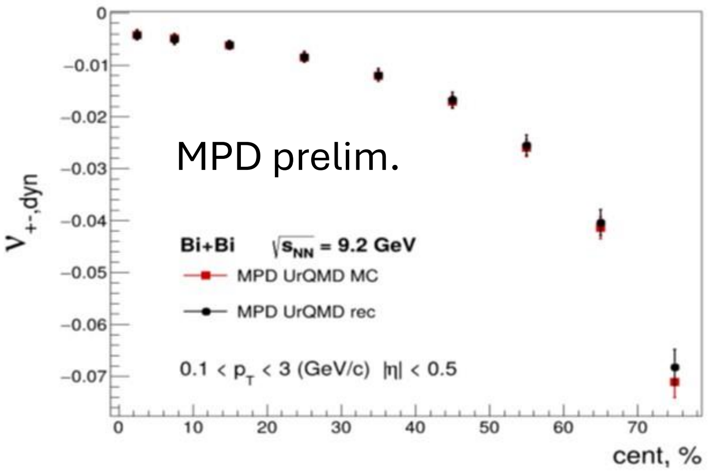


- The efficiency corrected cumulant ratios of net-protons and net-kaons are in good agreement with model
- MPD track reconstruction and PID performance allow us the study of fluctuations of conserved charges at NICA with good precision → high statistics data are needed

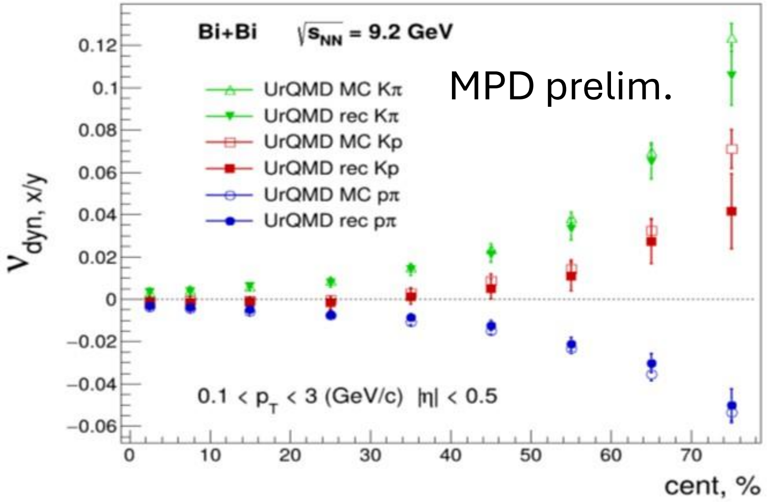
$C_3/C_2 = S\sigma \quad S = (\delta N)^3/\sigma^3$



$$\nu_{dyn}[+,-] = \frac{\langle N_+(N_+-1)\rangle}{\langle N_+\rangle^2} + \frac{\langle N_-(N_--1)\rangle}{\langle N_-\rangle^2} - 2\frac{\langle N_+N_-\rangle}{\langle N_+\rangle\langle N_-\rangle}$$



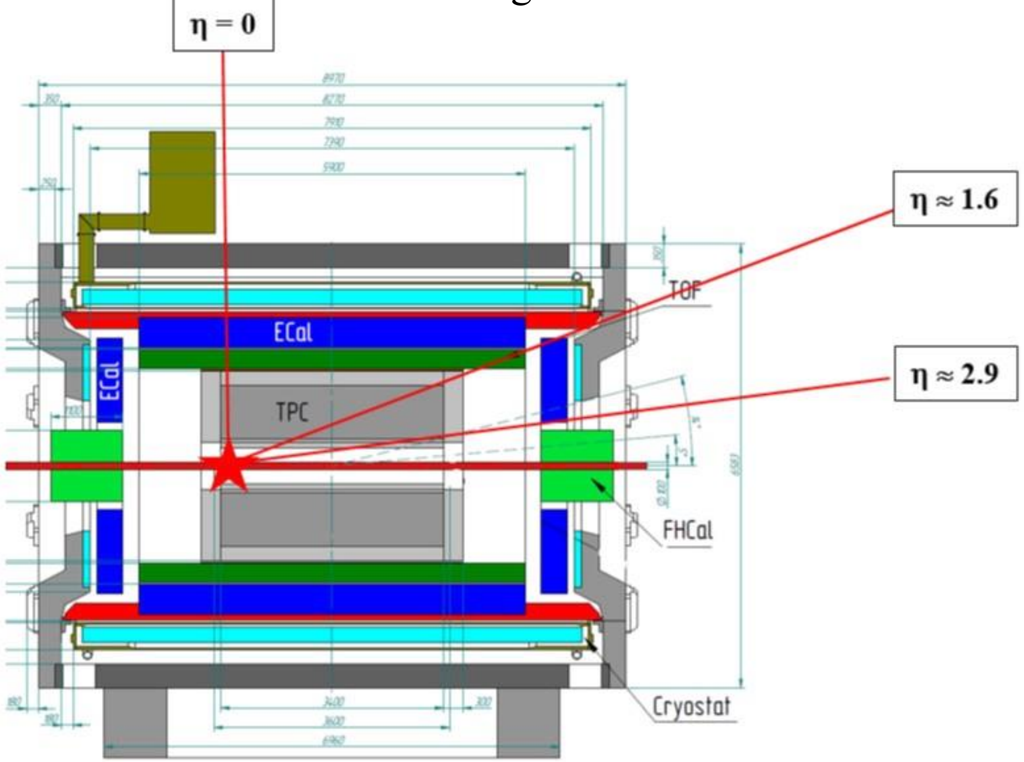
$$\nu_{dyn,K\pi} = \frac{\langle N_K(N_K-1)\rangle}{\langle N_K\rangle^2} + \frac{\langle N_\pi(N_\pi-1)\rangle}{\langle N_\pi\rangle^2} - 2\frac{\langle N_K N_\pi\rangle}{\langle N_K\rangle\langle N_\pi\rangle}$$



NICA/MPD operational modes during the commissioning phase (2025-26)

NICA FirstDay parameters:

- ^{124}Xe, E_{beam} =3.4A GeV, Luminosity up to 10^{26}
- Collider (CLD) and Fixed target (FXT) operation modes at MPD start-up $\sqrt{s}$ = 7 (CLD), 3 (FXT) GeV
- Estimated data set volume up 10^8 Events
  - FXT with a wire-target at z ~ -100 cm



MPD in 2025-26:

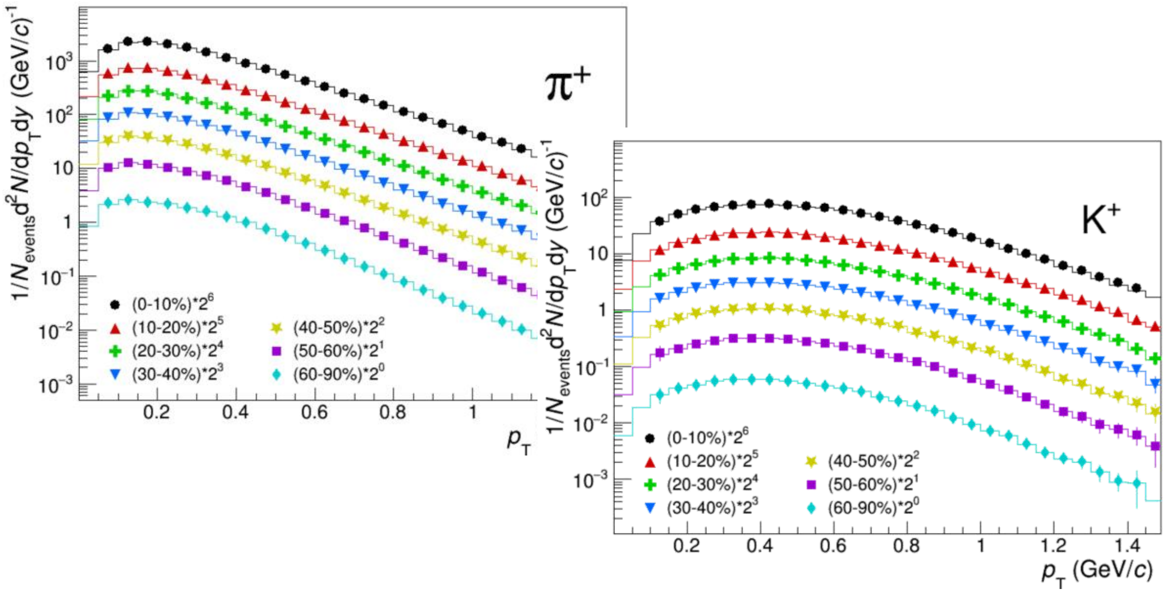
- MPD assembly → calibration and alignment runs (laser and cosmic)
- MPD in the RUN position → beam tuning and start of data taking

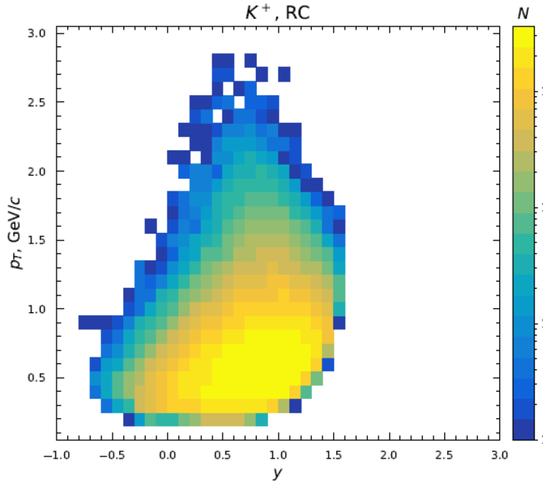
MPD tasks during the First Day data taking:

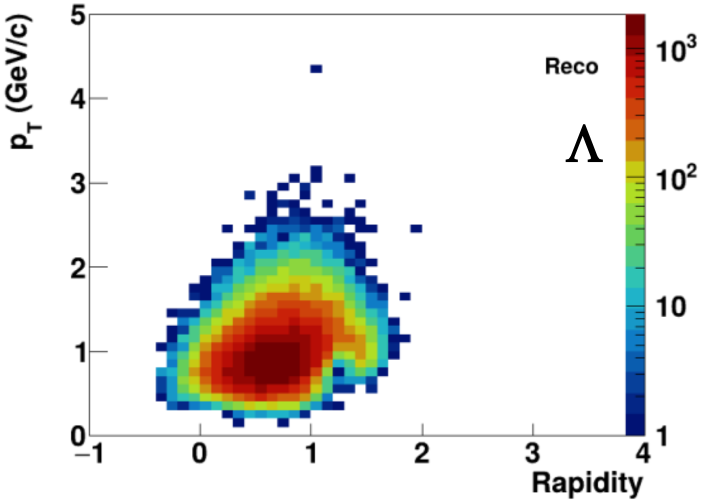
- Estimation of the triggering efficiency, event centrality classes, momentum resolution, reaction plane
- Estimate of total particle multiplicity density and transverse energy
- Measurement of basic observables robust against less precise particle ID: elliptic and directed flow, particle/antiparticle ratios, two-pion interferometry, hyperon production (via secondary vertexing w/o PID)
- After calibration of MPD PID responses: continuation with the MPD program with identified hadrons: particle spectra, yields and ratios, hyperons and resonances with final efficiency, correlation and fluctuation measurements

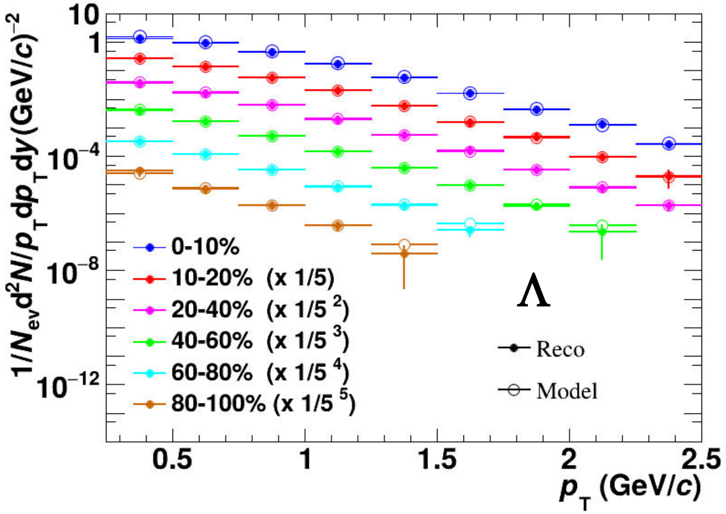
MPD feasibility study for the Fixed-Target Mode

- MPD feasibility studies using large-scale Monte Carlo productions for Xe+W at T=2.5A GeV

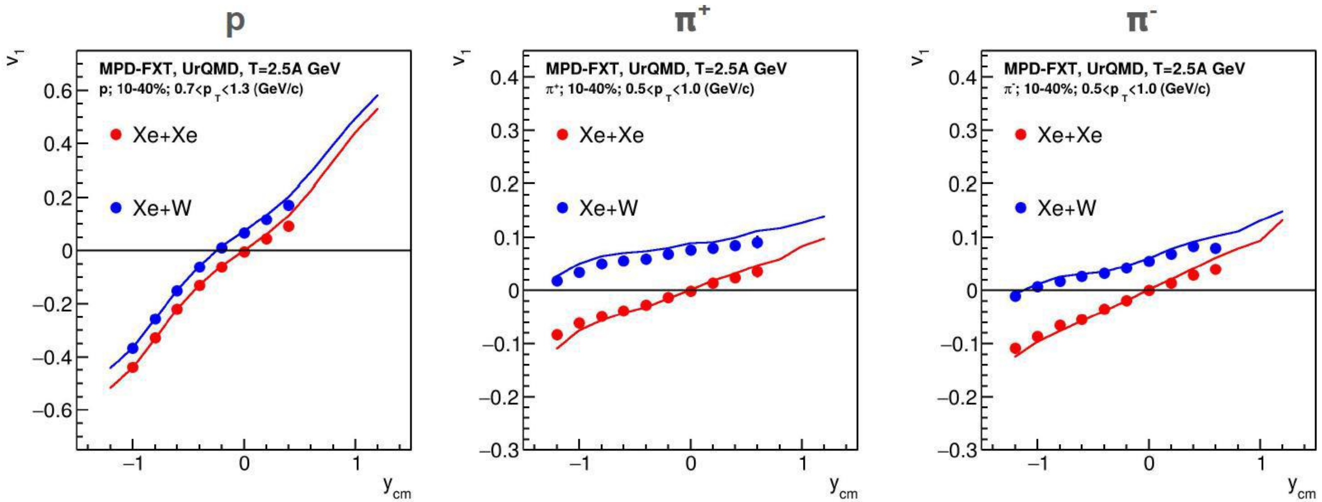








Talk of V.Riabov on Sat. 05/07 at 14:50



Talk of P.Parfenov on Sat. 05/07 at 14:30

Summary

- Intensive preparations for the start of the MPD physics program at NICA is ongoing
- NICA collider is in the commissioning phase
- MPD detector assembly & commissioning in 2025-26
- Extensive program of physics feasibility studies, preparation of software and analysis infrastructure for data taking & analysis (>10 MPD talks at NUCLEUS-2025)

Thank you for your attention!