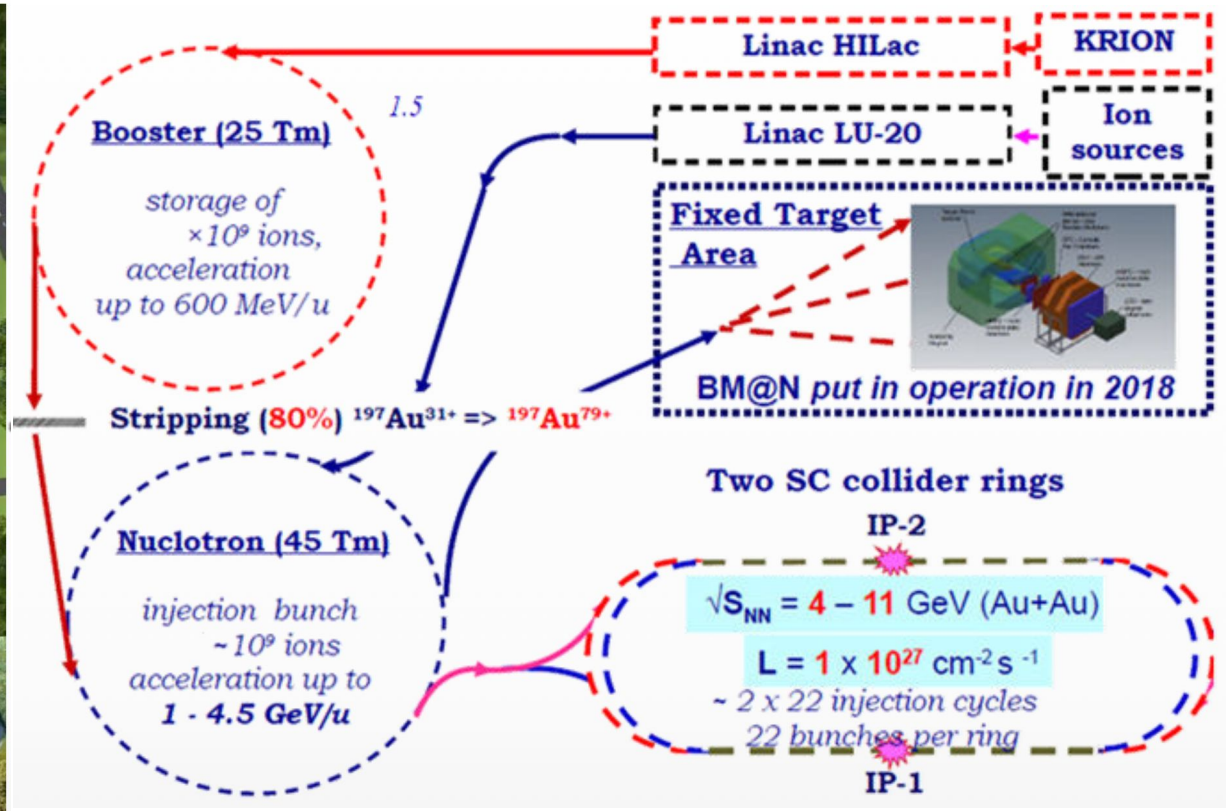
Status of the MPD experiment at NICA

P. Parfenov (JINR, NRNU MEPhI) for the MPD Collaboration

Particle Physics at Intermediate and High Energies
2-5 June 2026

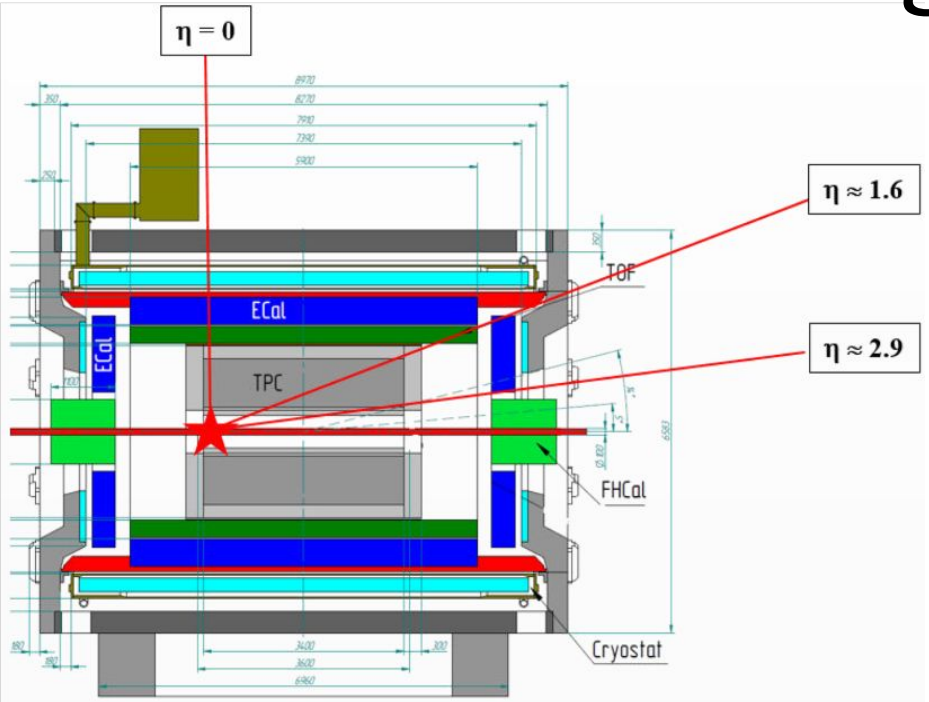
This work has been supported by the Ministry of Science and Higher Education of Russian Federation, Project Fundamental and applied research at the NICA (JINR) megascience experimental complex FSWU-2025-0014

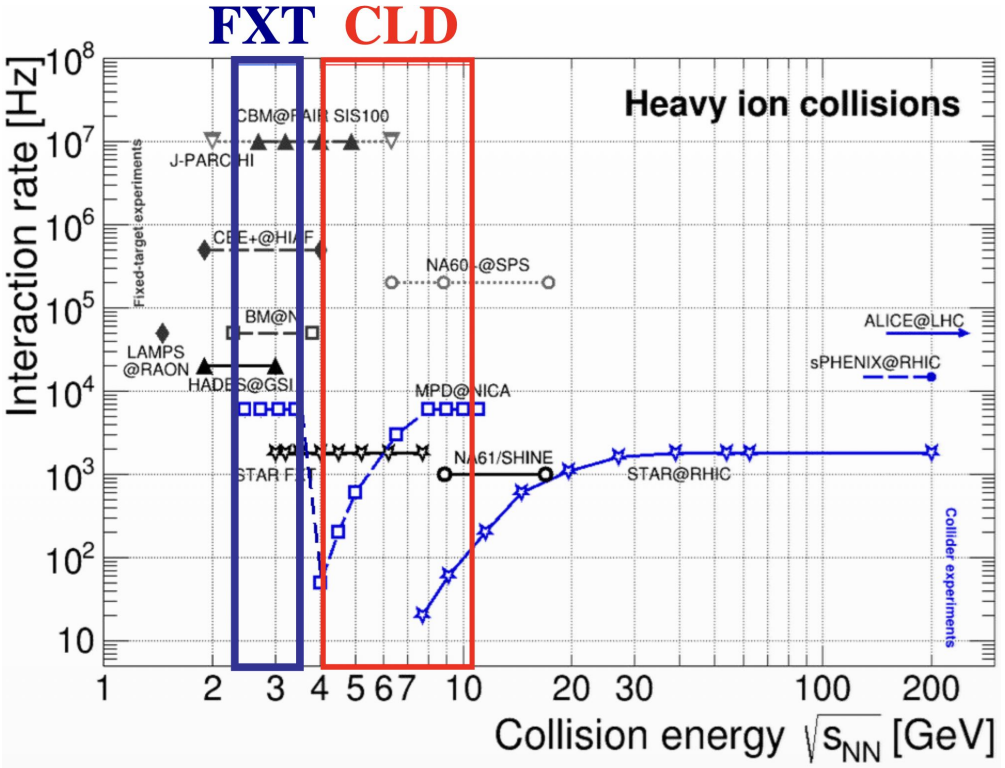
NICA Project



- **The first megascience project in Russia, which is approaching its full commissioning:**
  - **Baryonic matter at Nuclotron (BM@N) –** already running in the fixed-target mode
  - **Multi-Purpose Detector (MPD) –** planned start of operation at the end of 2026
  - **Spin Physics Detector (SPD) –** operating on polarized deuterons later on

MPD – fixed-target mode





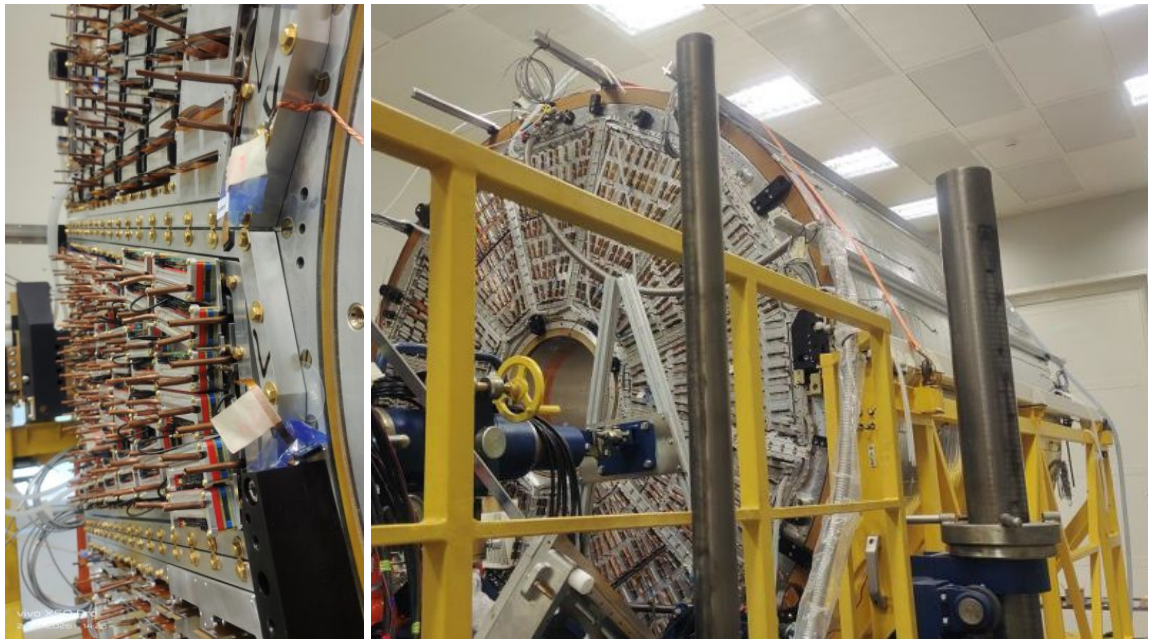
- **Collider mode (MPD-CLD):** two beams, $\sqrt{s_{NN}}$ = 4-11 GeV
- **Fixed-target mode (MPD-FXT):** one beam, thin (~50-100 μm) wire close to the edge of the central barrel:
  - Extends energy range of the MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV – overlap with HADES, BM@N, and CBM
  - Allows to maintain high interaction rate at lower beam energies compared to MPD-CLD
- **Expected beams at the first year(s) of operation:**
  - MPD-CLD: Xe/Bi+Xe/Bi at $\sqrt{s_{NN}}$ ~ 7 GeV, reduced luminosity (~50 Hz interaction rate)
  - MPD-FXT: Xe/Bi +W at $\sqrt{s_{NN}}$ ~ 3 GeV

MPD subsystem status (I)

Magnet and cryogenics

- Cooled the magnet to LN2 and LHe temperatures: nominal MF of 0.57T had been reached
- Magnet is fully operational
- MF measurements are planned before TPC installation

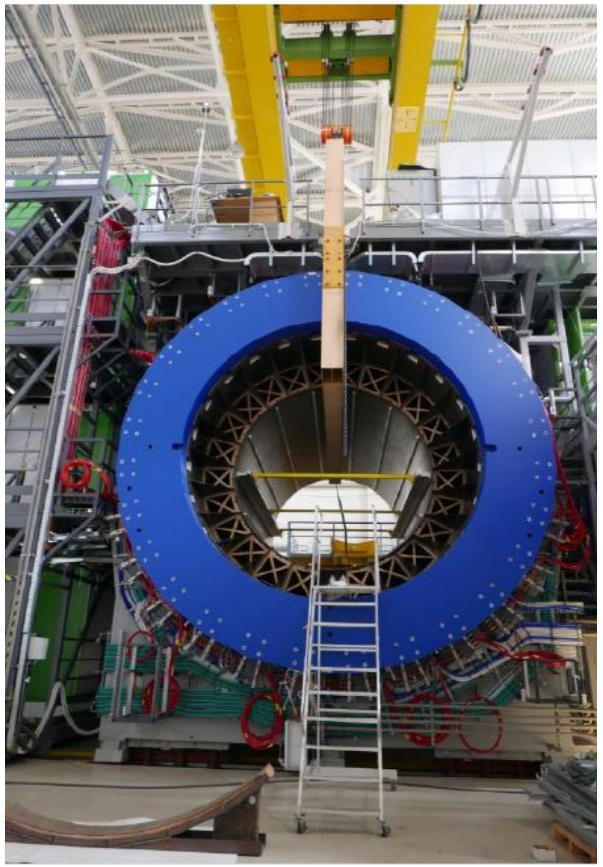
TPC – central tracker



- Gas volume assembled and tested for leaks and HV
- 24 Read-Out-Chambers (ROC) installed
  - Operational HV has been applied to the membrane and ROC (Cathode), cosmics detected

MPD subsystem status (II)

Support structure



Carbon fiber power frame is installed in the magnet

- sagita ~5 mm at full load
- rails for TPC and TOF are installed

TOF

All 28 modules are assembled, tested and ready for installation

Beam luminosity detector

Operated at collider start-up

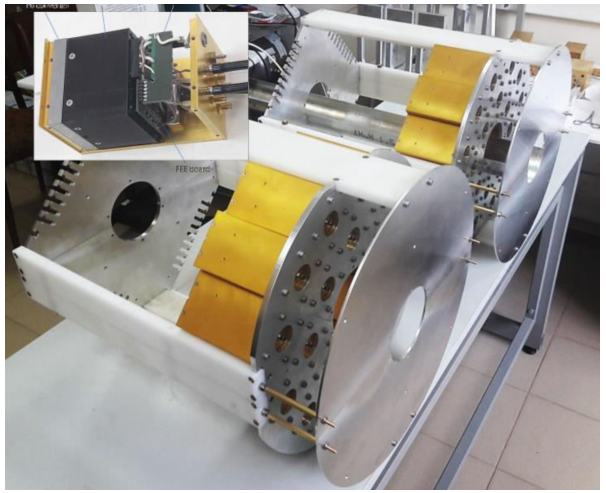
ECAL

- Manufactured together with universities of China
- Installation of ECAL half-sectors is ongoing
  - 60% of half-sectors have been installed

FHCal

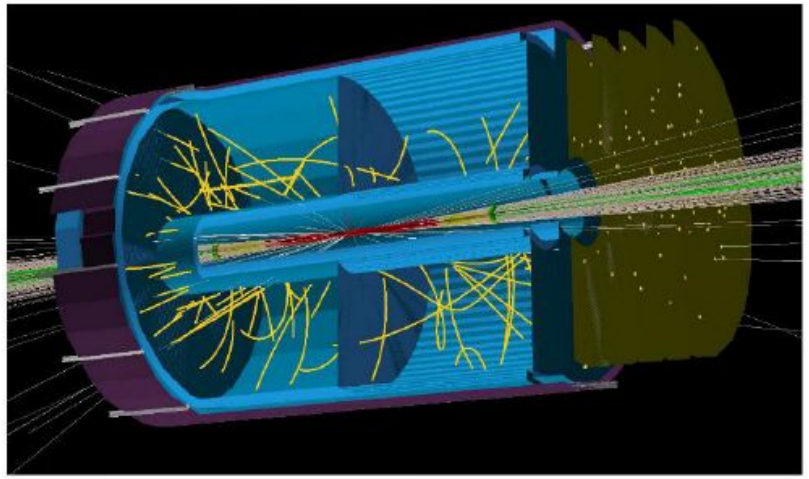
FHCal assembled on the platform

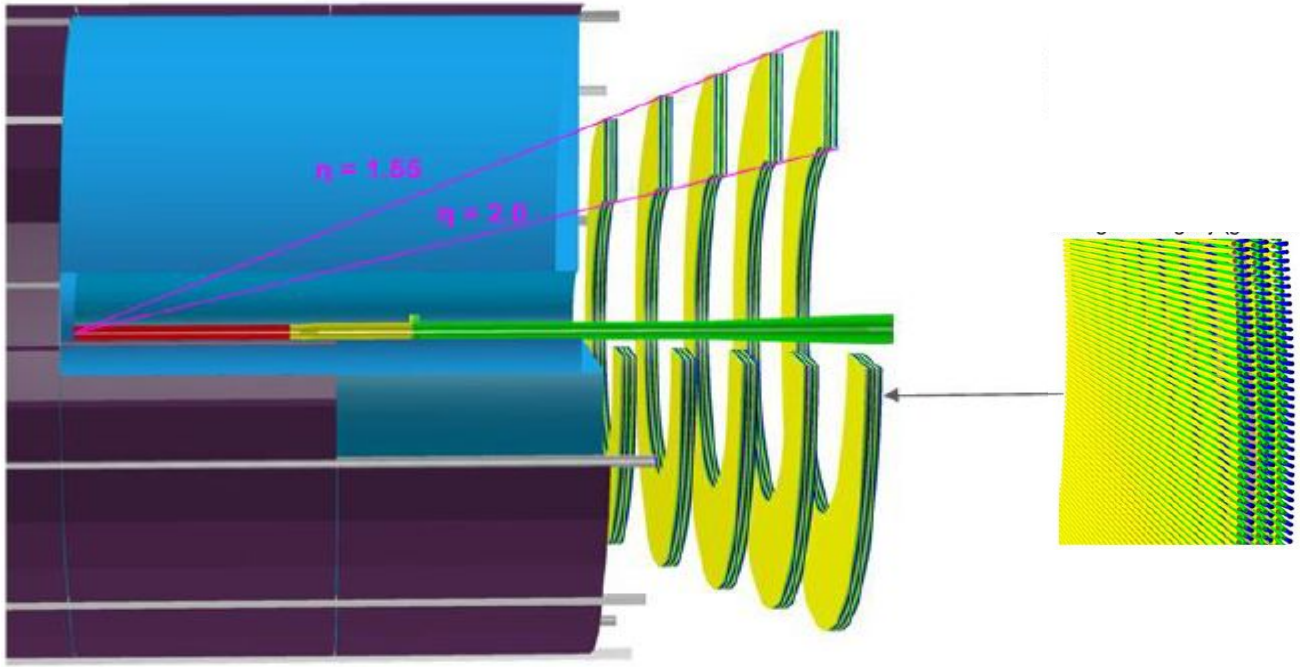
FFD



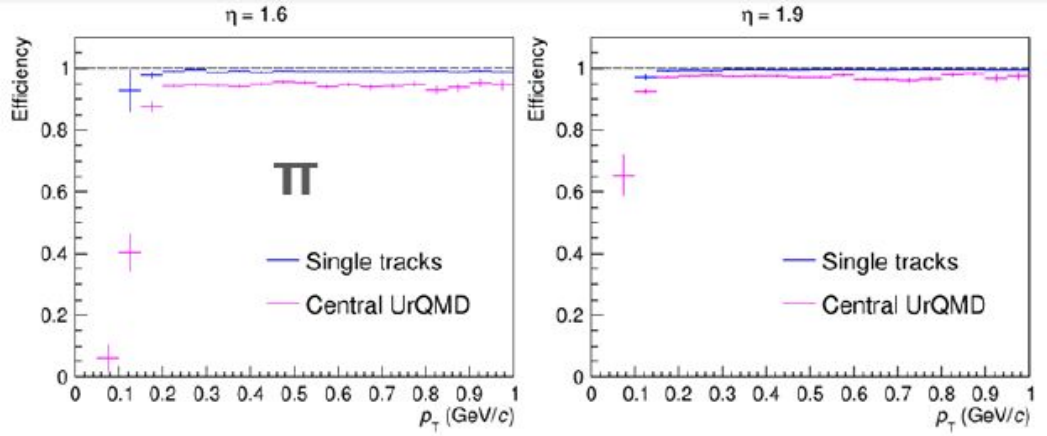
Cherenkov modules, mechanics for installation in container with the beam pipe are available

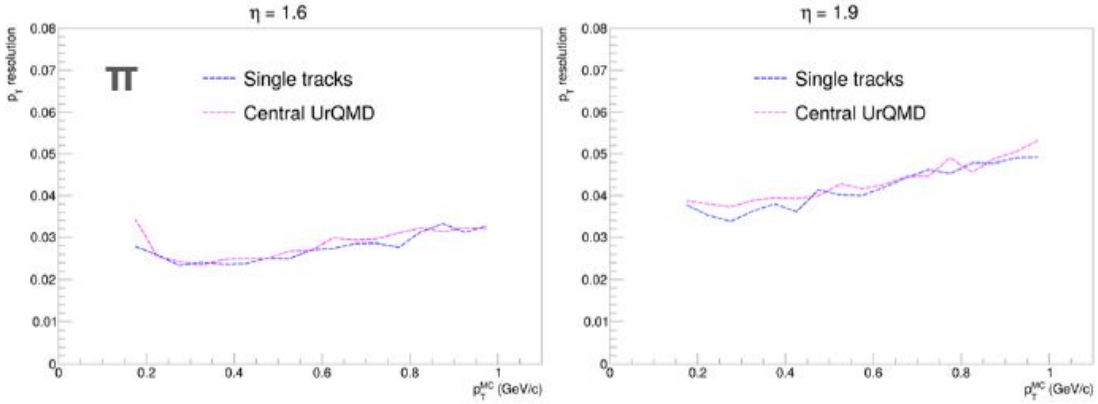
Development of the Forward Spectrometers





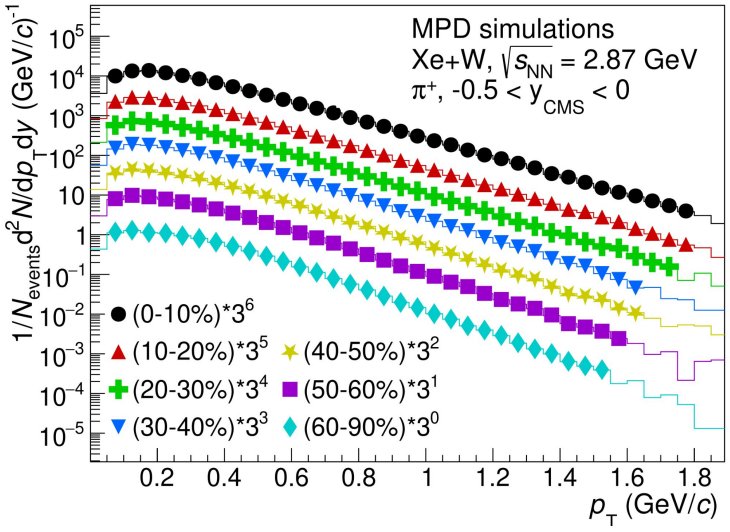
- 9 layers per station with RUV stereo angles: 0°,±7°,...
- Acceptable radiation length ~0.15-0.2% per station
- Total straws for 2 sides: ~66k channels

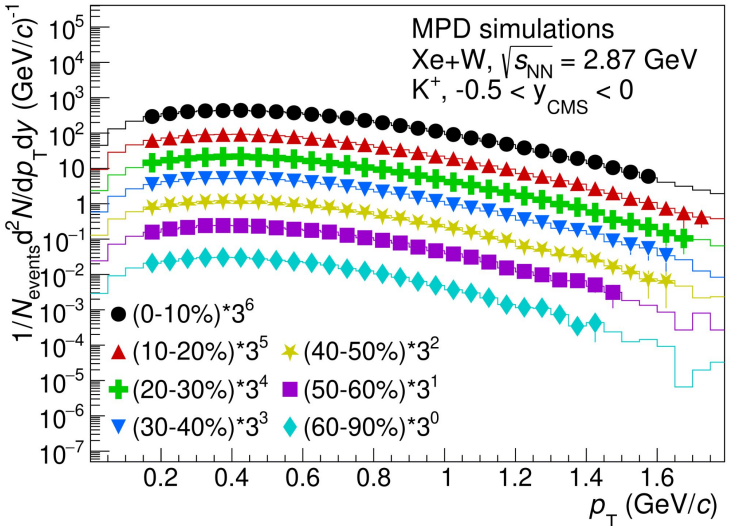


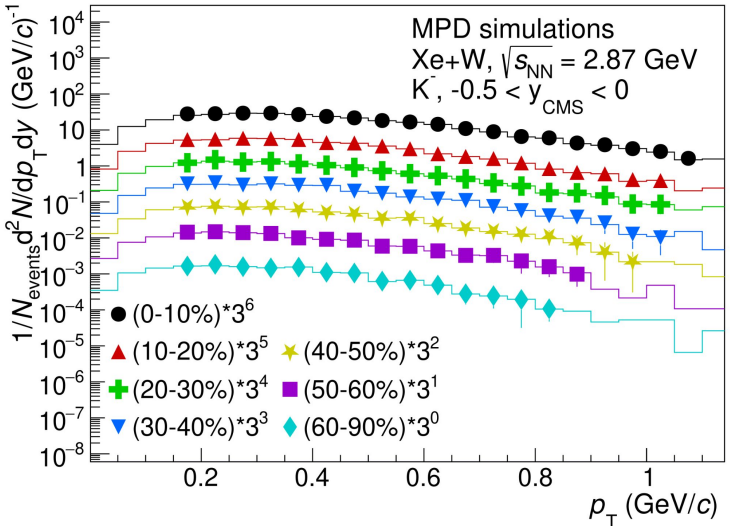


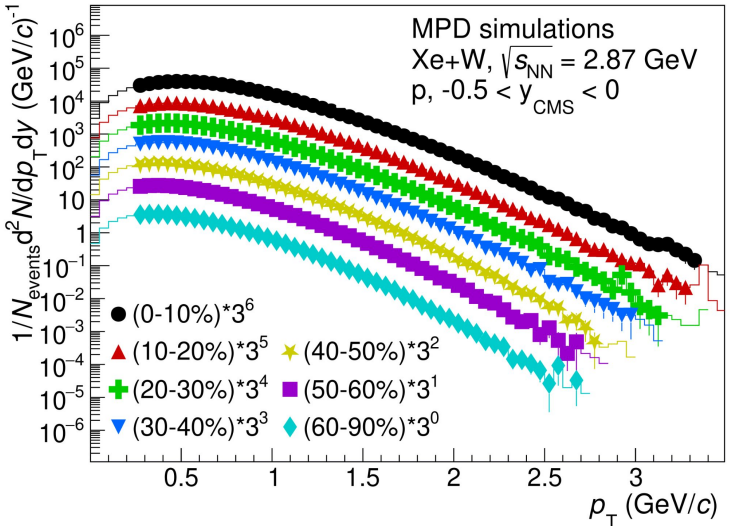
Optimizing technological solutions to ensure good performance - ongoing

Charged identified hadron production



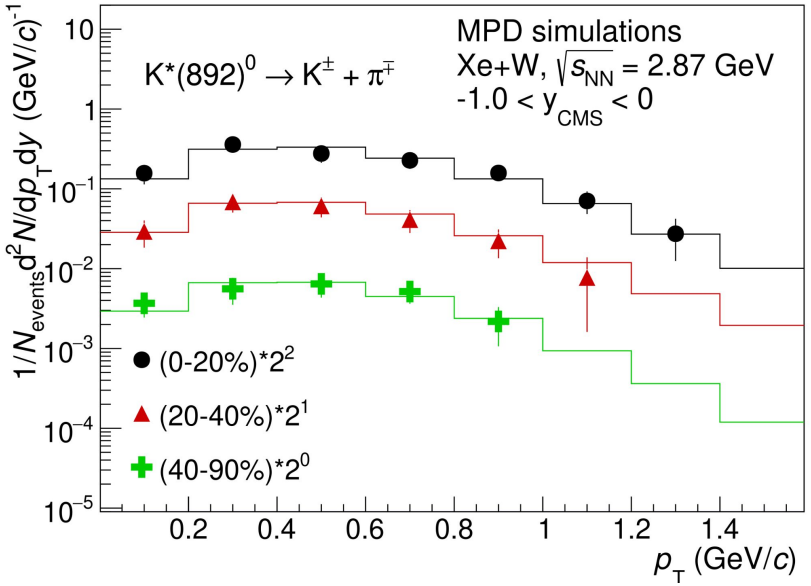


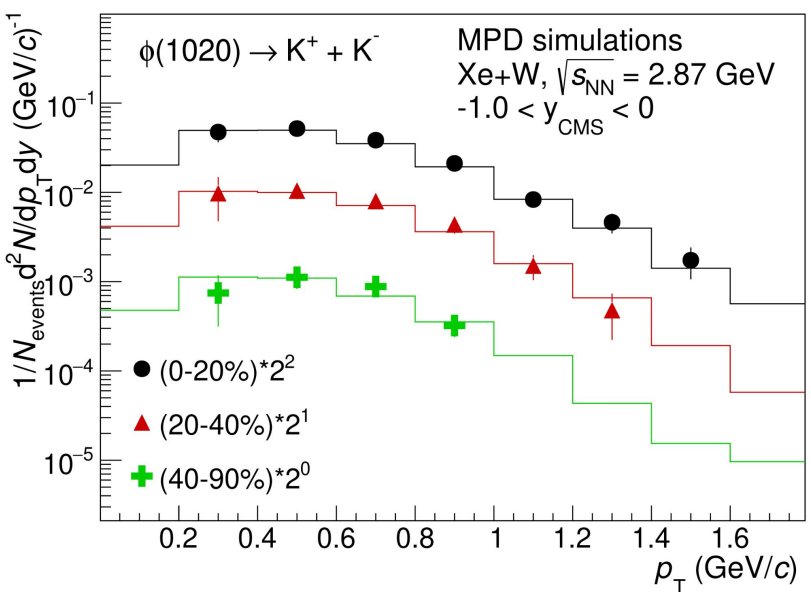


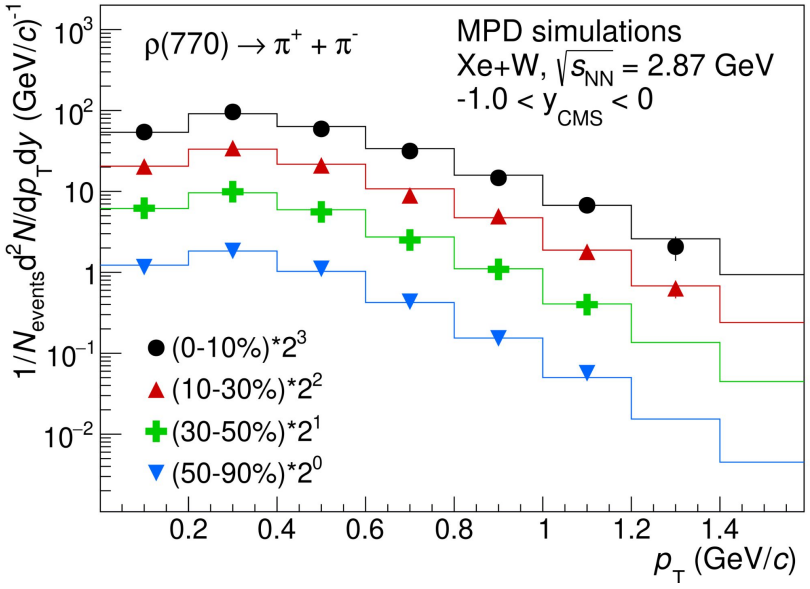


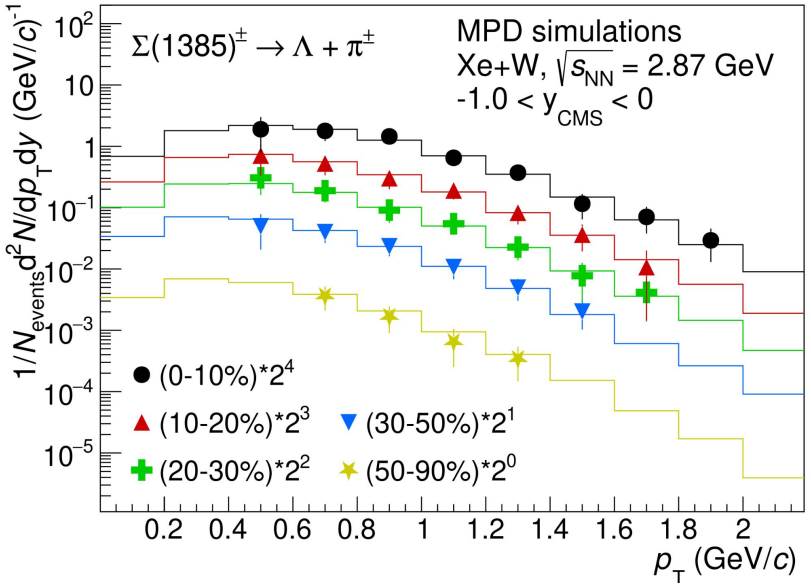
- Rapidity coverage: -1.3 < y_{CMS} < 0
- Spectra at mid-rapidity cover the p_T ranges that correspond to production of over 95% (85%) of the total $\pi^{\pm}$(p) yields and 93% (85%) of K^+(K^-)
  - Robust basis for extracting the integrated yields

Resonance production



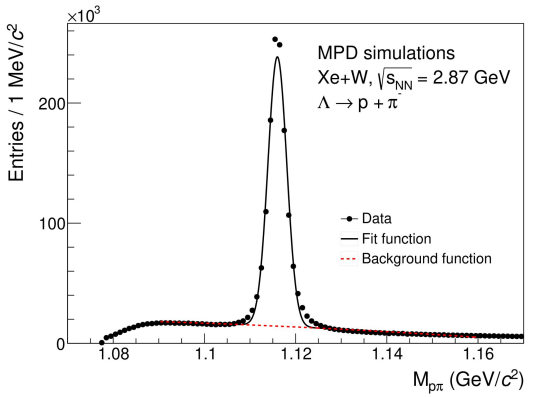


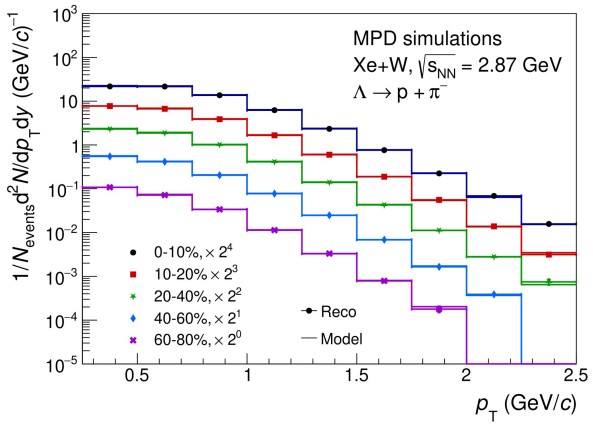


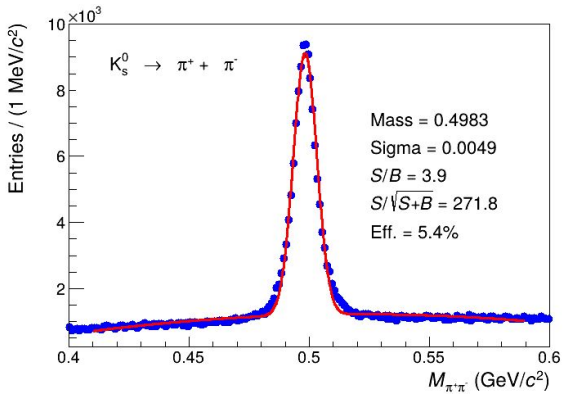


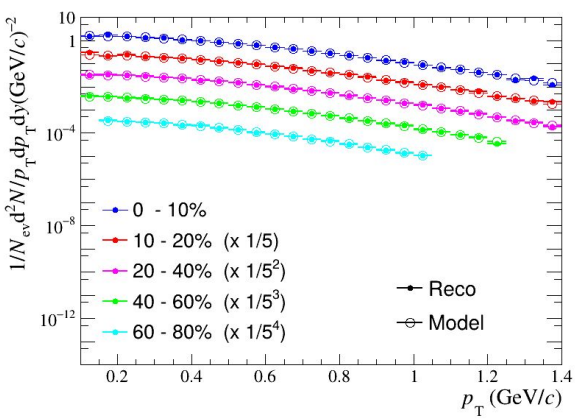
- Production of the resonances is possible from low/zero p_T
- Will be able to study centrality dependent production of ρ (770), $K^*(890)^0$, $K^*(892)^{\pm}$, ϕ(1020), and $\Sigma(1385)^{\pm}$

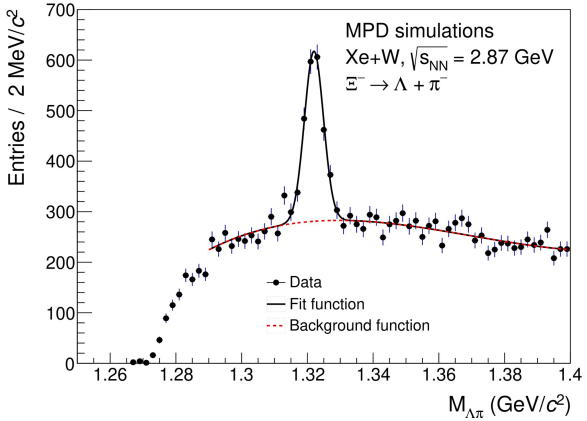
Weak decays of K_s, Λ, and Ξ^-

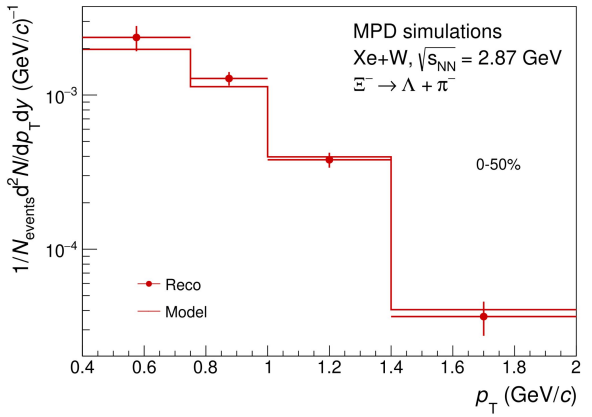








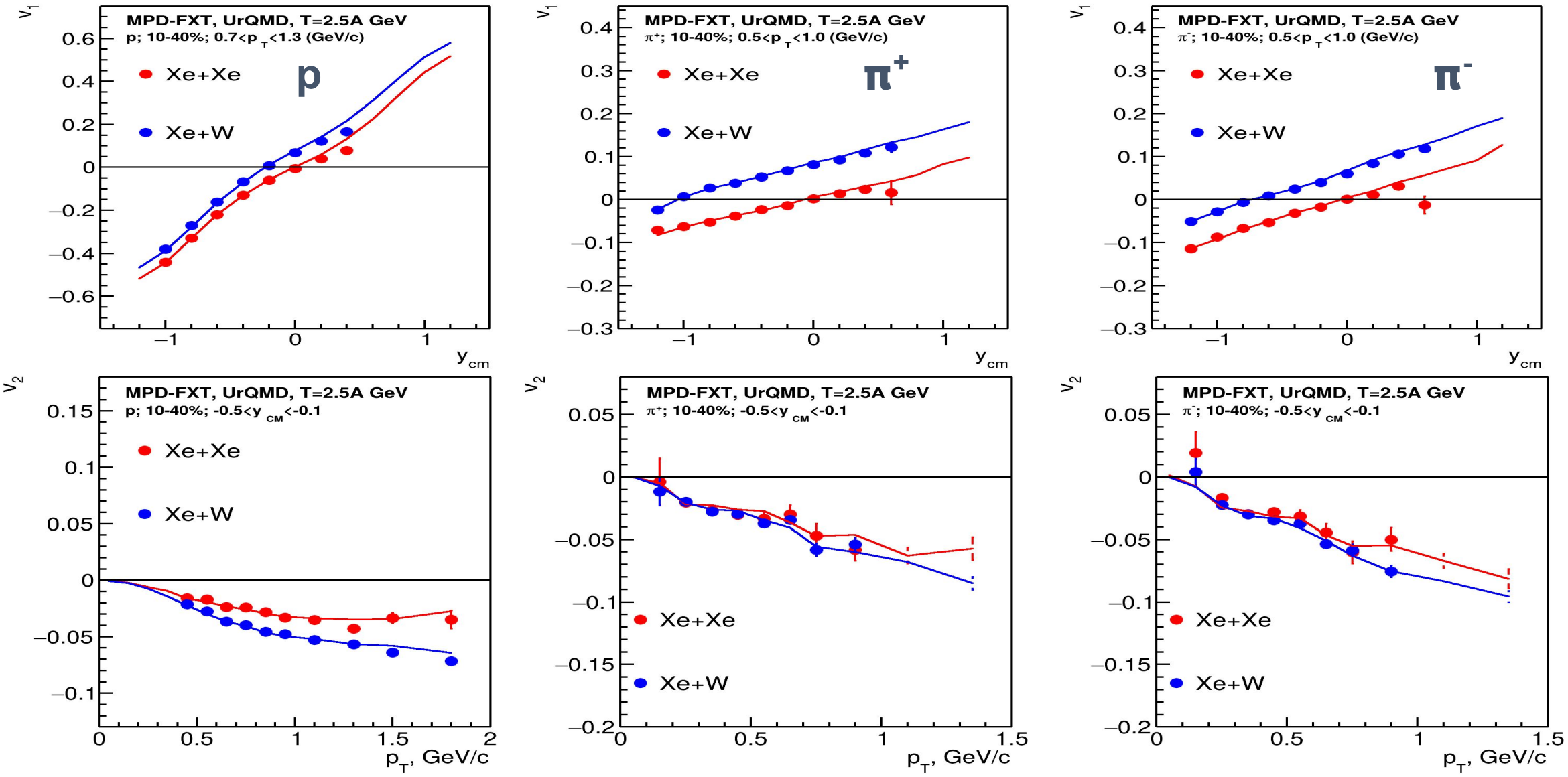




- Reliable reconstruction of weak decays using topology selections
- Centrality-dependent study in a wide p_T range is possible

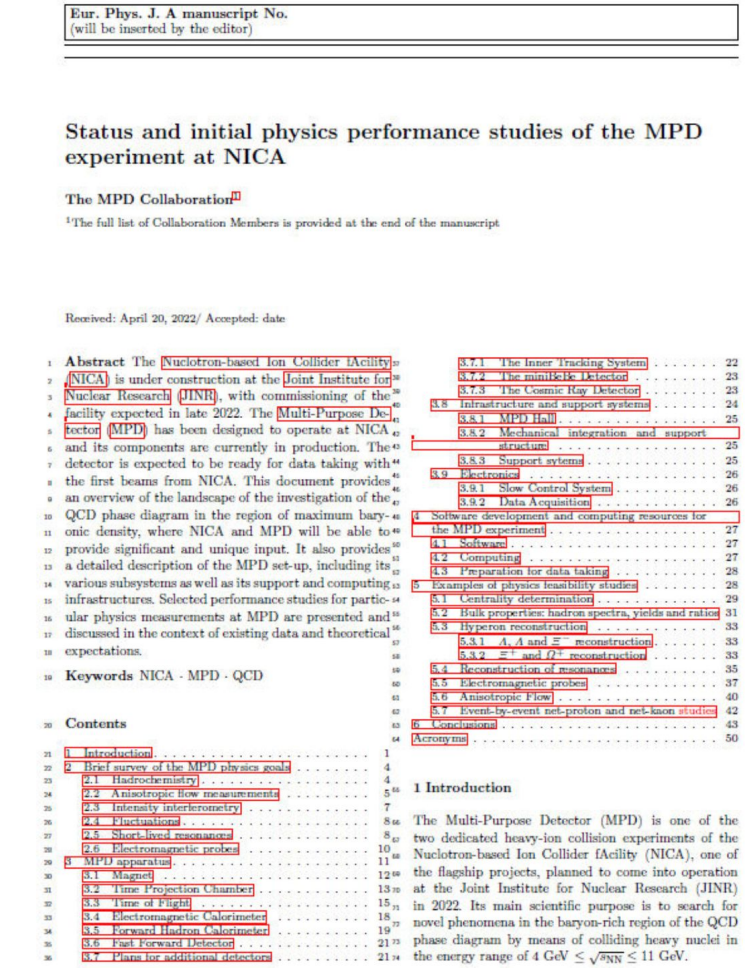
Anisotropic flow at MPD-FXT

markers - reco; lines - model



Good agreement for protons and pions for y<0.5

Publication activity



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

Received: April 20, 2022/ Accepted: date

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

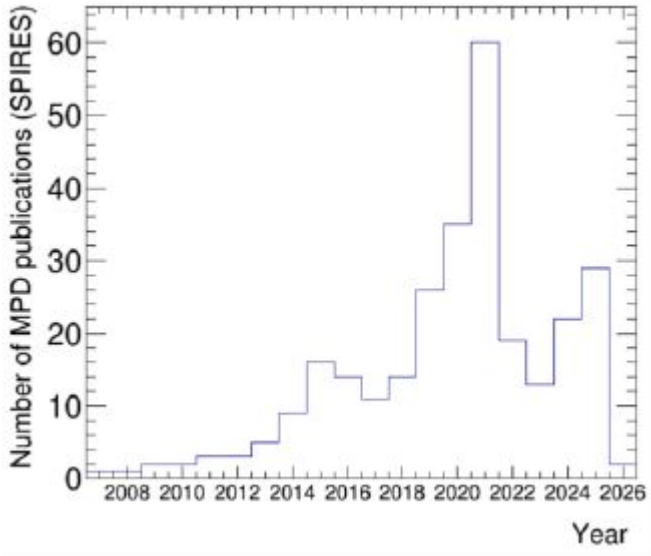
1 Introduction

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.

Nuclear Physics Revista Mexicana de Física **71** 041201 1–45 JULY-AUGUST 2025

MPD physics performance studies in Bi+Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV

R. Abdulin[20], V. Abgaryan[1], R. Acharya[16], K.G. Afanaciev[10,12], S.V. Afanasiev[10], G. Agakishiev[16], E.I. Alexandrov[16], I.N. Alexandrov[16], M. Alvarado-Hernandez[14], D.I. Andreev[16], S.V. Andreeva[16], T.V. Andreeva[16], E.V. Andronov[28], N.V. Anfimov[16], A. Anikeev[21], A.V. Anufriev[28], A.A. Aparin[16], E. Arteche-Diaz[25], V.I. Astakhov[28], T. Aushev[29], S.P. Avdeev[16], G.S. Averichev[16], A.V. Averyanov[16], A. Ayala[14], V.N. Azorskiy[16], L. Bavichev[22], V.A. Babkin[16], P. Balkin[19], A.I. Balandin[16], N.A. Balashov[16], A. Barsnov[23], D.A. Baranov[16], N.V. Baranova[31], E.V. Barutov[13], N. Barbashina[21], V. Barbasova[29], V.M. Baryshnikov[16], K.D. Basharina[16], A.E. Baskakov[16], V.G. Bayev[13], A.G. Bazhazhin[16], S.N. Bazylev[16], P. Beletsky[25], S.V. Belokurova[28], A.V. Belyaev[16], E.V. Belyaeva[16], D.V. Belyakov[16], Y. Berchikov[24], F. Berezov[25], M. Bhattacharjee[16], W. Bietenholz[14], D. Blau[16], G.A. Bogdanova[31], D.N. Bogoslovsky[16], I.V. Boguslavski[16], E.A. Bondar[13], E.E. Boos[21], A. Bortina[10], A. Brandin[24], S.A. Bulychjov[19], V. Bundetnaya[23], N. Burmasov[20], M.G. Buryakov[16], J. Buza Jr.[16], A.V. Butenko[16], S.G. Buzin[16], A.V. Bychkov[16], Z. Cao[26], C. Caballos-Sánchez[14], V.V. Chalyshev[16], V.F. Chepurnov[16], V.I.V. Chepurnov[16], G.A. Cheremukhina[16], A.S. Chernyshev[24], E. Cuautle[14], A. Demanov[23], D.V. Dementiev[16], D. Derkach[8], A.V. Dmitriev[16], E.V. Dolbilina[16], V.H. Dodokhov[16], A.G. Dolbilov[16], I. Domínguez[6], D.E. Donetz[16], V.I. Dronik[16], A.Yu. Dubovtsev[16], P.O. Dulov[16,30], V.B. Dunin[16], A. Dyachenko[29], A.A. Efremov[16], D.S. Egorov[16], V.V. Elsha[16], N.E. Emelianov[16], J. Erkenova[23], G.H. Eyyubova[16], A. Echilov[20], D. Fang[7], O.V. Fateev[16], O. Fedin[28], A.I. Fedosimova[12], Yu.I. Fedotov[16], A.S. Fedotov[16], J.A. Fedotova[27], A.A. Fedunin[16], S. Feng[26], G.A. Feofilov[28], I.A. Filippov[16], G. Fonseka[30], M.A. Gagarova[16], K.A. Galaktionov[28], Ya.D. Galkin[27], A.S. Galoyan[16], Ch. Gao[17], P.E. García-González[14], O.P. Gavrishuk[16], N.S. Gerasimov[16], K.V. Gertsenberger[16], N. Gevorgyan[1], Y. Ghonesm[30], O. Golosov[10], V.M. Golovatyuk[16], M. Golubeva[23], A.O. Golunov[16], I. Goncharov[22], N.V. Gorbunov[10], P. Gordeev[19], I.P. Gorelikov[16], H. Grigorian[1], P.N. Grigoriev[16], F. Guber[23], D. Guo[17], A.V. Guskov[16], D. Han[24], W. Han[13], W. He[7], L.A. Hernández-Rosas[3], M. Herrera[5], S. Hnatic[16], M. Hnatic[25], M. Huang[26], S.A. Ibramova[12], D.M. Idrisov[16], T.K. Idrisova[12], Z.A. Igamkulov[16], S.N. Igolkin[28], A.Yu. Isupov[16], D. Ivanishchev[31], A.V. Ivanov[16], A. Ivashkin[16], J. Jiao[26], I. Jodochnikov[1], S.I. Kakurin[16], N.I. Kalinichenko[28], A. Kamkin[29], M.N. Kapishin[16], D.E. Karmanov[24], N. Karpushkin[10], I.A. Kashunin[16], Y. Kasumov[22], A.O. Kechechyan[16], G.D. Kekelidze[16], V.D. Kekelidze[16], A. Khanzadeev[20], P.I. Kharlamov[21], G.O. Khodzhibagiyan[16], E. Kidonova[2], V.A. Kireyev[16], Yu.T. Kiryushin[16], L. Kochenda[20], O.L. Kodolova[21], A.A. Kokorev[16], A.O. Kolesnikov[16], V.I. Kolesnikov[16], N. Kolesnyeyev[16], A.A. Kolozhvari[16], V. Kondratiev[26], V.V. Korenkov[16], M.O. Korolev[24], V.L. Korotkikh[24], A.I. Kostylev[18], D. Kotov[20,28], V.N. Kovalenko[28], I. Kozmin[20], V.A. Kramarenko[16], A. Kravtsova[29], P. Kravtsov[20], Ya.F. Krechetov[24], I.V. Kruglova[16], V.A. Krylov[16], A.V. Krylov[16], E. Krysbev[16], A.P. Kryukov[31], S.N. Kuklin[16], V.V. Kulikov[18], A.A. Kulikovskaya[10], A.V. Kunts[27], E. Kurbatov[8], A. Kurepin[16], V. Kushov[19], V.A. Kuzmin[24], A. Kyrinova[20], D.E. Lanskoy[21], N.A. Lashmanov[16], R. Lednicky[16], V.V. Leontev[16], I.A. Lebedev[12], L. Li[24], P. Li[26], S. Li[26], T.Z. Ligdenova[16], A.V. Litomin[27], E.I. Litvinenko[16], D. Liu[26], V.I. Lobanov[16], Yu.Ya. Lobanov[16], S.P. Lobastov[16], I.P. Lokhtin[21], J.R. Lukstins[16], D. Lancanov[24], A. Lobanov[24], P. Lu[26], I. Luna-Reyes[14], X. Luo[17], Y. Ma[7], D.T. Madigozhin[16], A.A. Makarov[16], V.I. Makumenkova[16], A.I. Malakhov[16], M. Malsen[29], I.A. Maldonado-Cervantes[16], V. Maleev[20], I.V. Malikov[16], N.A. Maltsev[16], N.A. Makarov[28], M. Maksimov[29], M.A. Martemianov[19], P. Martinez-Torres[15], M.A. Matsyuk[16], M. Mechedeva[27], D.I. Melikov[31], D.G. Melnikov[16], M.M. Merkin[21], S.P. Mertz[16], I.N. Meshkov[16], V.V. Mialkovski[16], I.I. Migulina[16], K.F. Mikhaylov[16,30], G.D. Milnov[16], J. Milosevic[27], Yu.I. Minaev[16], S.A. Mitsyn[16], G.V. Meshcheriakov[16], N.A. Molokanova[16], S. Morozov[10], A.A. Moshkin[16], S.A. Movchan[16], A.N. Moybenko[16], K.A. Mukhin[15], Ya.A. Murin[16], S. Musin[23], G.G. Musulmanbekov[16], V.V. Mytnin[16], E.E. Murovkin[16], L. Naddeo[27], R.V. Nagdasev[16], Ya. Naryshkin[16], A.V. Nechaevskiy[16], V.A. Nikitin[16], V.A. Novoselov[16], I.A. Oleks[16], A.G. Olshevski[16], O.E. Orlov[16], V. Papoyan[1], P.E. Parfenov[16,21], S.S. Parzhitsky[16], M.E. Patiño-Salazar[14], S.V. Patrazeva[16], V.A. Pavlyutsevich[16], I.S. Pelevanyuk[16], V.A. Penkin[16], D. Perevalov[16], D.V. Peshekhonov[16], V.A. Petrov[16], V.V. Petrov[29], A.V. Pilnr[16], A. Pilyugin[1], S.M. Piyadin[16], M.N. Platonova[21], D.V. Podgainy[16], M. Poloskov[20], V.N. Popov[28], D.S. Potapov[16], D.S. Prokhorova[28], N.A. Prokoffev[28], D.I. Priakhina[16], I. Pshenichnov[10], A.M. Puchkov[28], N. Pukhaeva[22,16], A. Pyatigor[2], J. Qin[26], F. Ratnikov[8], A. Reva[16], V. Rekovic[27], M. Reyes-Gutiérrez[14], S. Reyes-Peña[14], A. Riabov[29], V. Riabov[20], Ya. Riabov[20], S.P. Rode[16], A. Rodríguez-Alvarez[15], O.V. Rogachevsky[16], V.Yu. Rogov[16], V.A. Rudnev[28], I.A. Rufanov[16], M.M. Rumyantsev[16], I. Rudzankou[29], Yu. Rusak[22], A.A. Rybakov[16], Z. Sadygov[16], A.U. Saenz-Trujillo[4], V.A. Samsonov[16], A.A. Savenkov[16], S. Savenkov[10], S.A. Sechkh[16], T.V. Senochkina[16], A.Yu. Semenov[16], B.N. Semenov[16], I.A. Semenova[16], V.Z. Serdyuk[16], S.V. Sergeev[24], A.S. Serikkanov[12], E.V. Serochkin[16], Yu. Shafnevich[27], D. Shapaev[24], O.M. Shaposhnikova[29], L.M. Shcheglova[31], M.E. Shopova[29], D.V. Shchegolev[20], A.V. Shchipunov[16], Y. Shen[26], A.D. Sheremetiev[16], A.I. Sheremetieva[16], S. Shi[17], M.O. Shitenkov[16], E.E. Shmanay[27], S.V. Shmatov[16], I.A. Shmyrev[28], A.A. Shmko[16], A.V. Shutov[16], V.B. Shutov[16], A.O. Sidorin[16], S.V. Smak[29], I.V. Slepnev[16], V.M. Slepnev[14], I.P. Slepov[16], I.A. Smelyanskiy[16], A.M. Snigirev[21], O.V. Sobol[24], A.N. Solomin[31], A.S. Sorin[16], G.G. Stiforov[16], I. Yu. Stolypina[16], E.A. Streletskaya[16], O.I. Streltsova[16], M. Strikhanov[28], T.A. Strizh[16], A. Strizhak[29],



- Overall 250+ publications (indexed by SPIRES)
- Collaboration papers:
  1. **Status and initial physics performance studies of the MPD experiment at NICA**
     Eur.Phys.J.A 58 (2022) 7, 140 (~ 50 pages)
  2. **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)

Third collaboration paper is in preparation

Summary

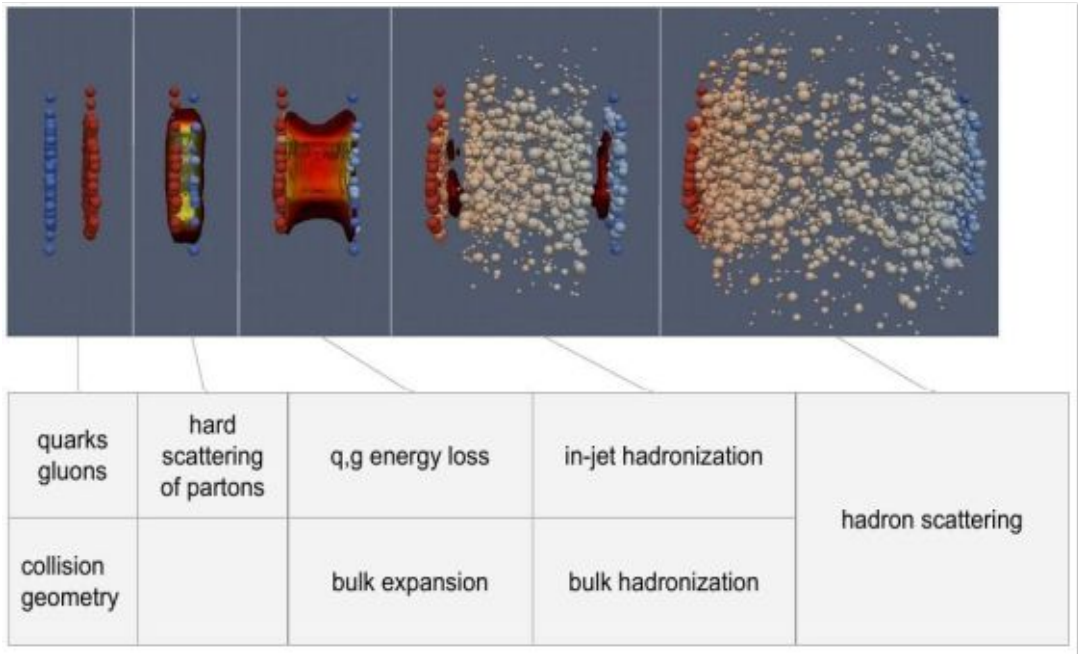
Thank you for your attention!

- MPD collaboration is steadily coming to final integration of the detector and first data taking on the beams from NICA
- Physics program for the first years of MPD data taking is formulated and two physics paper was published. Third paper under preparation.
- First operations of the MPD detector are expected at the end of 2026
- MPD will provide a unique opportunity for investigating properties of nuclear matter at maximal densities to map the QCD phase diagram, to search for phase transition and the Critical End Point

Backup

MPD physics feasibility studies

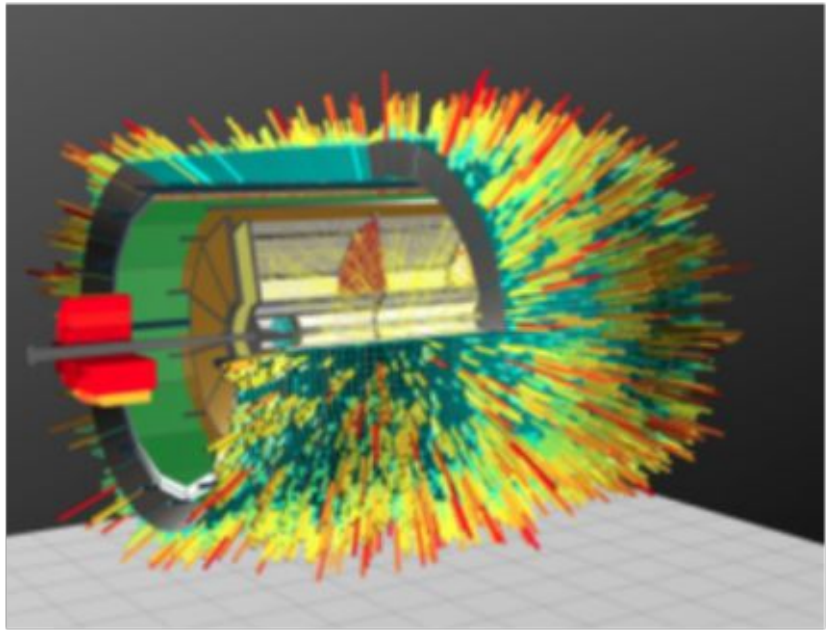
Event generator(s)



MpdRoot

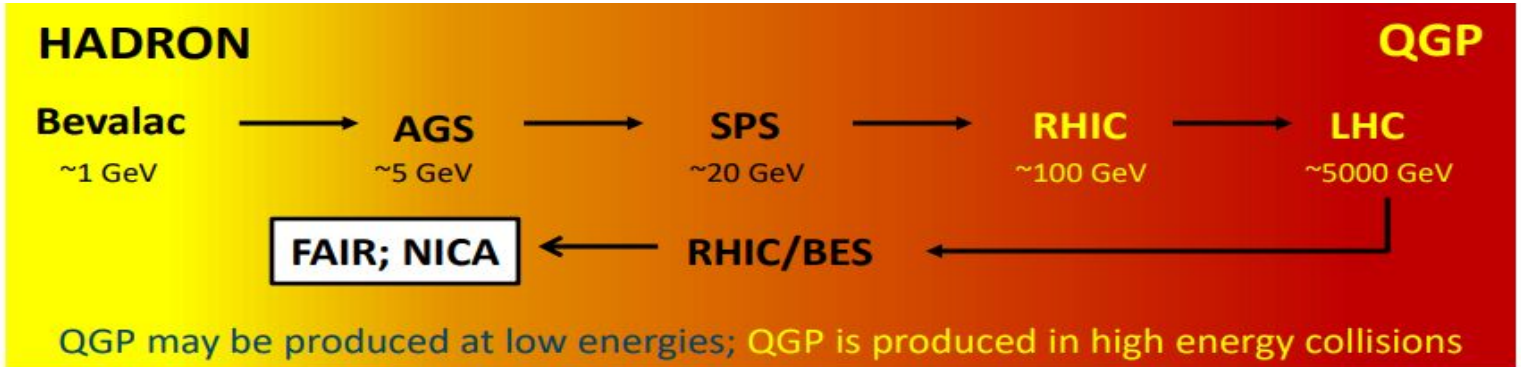
JINR MLIT

Particle propagation & detector response



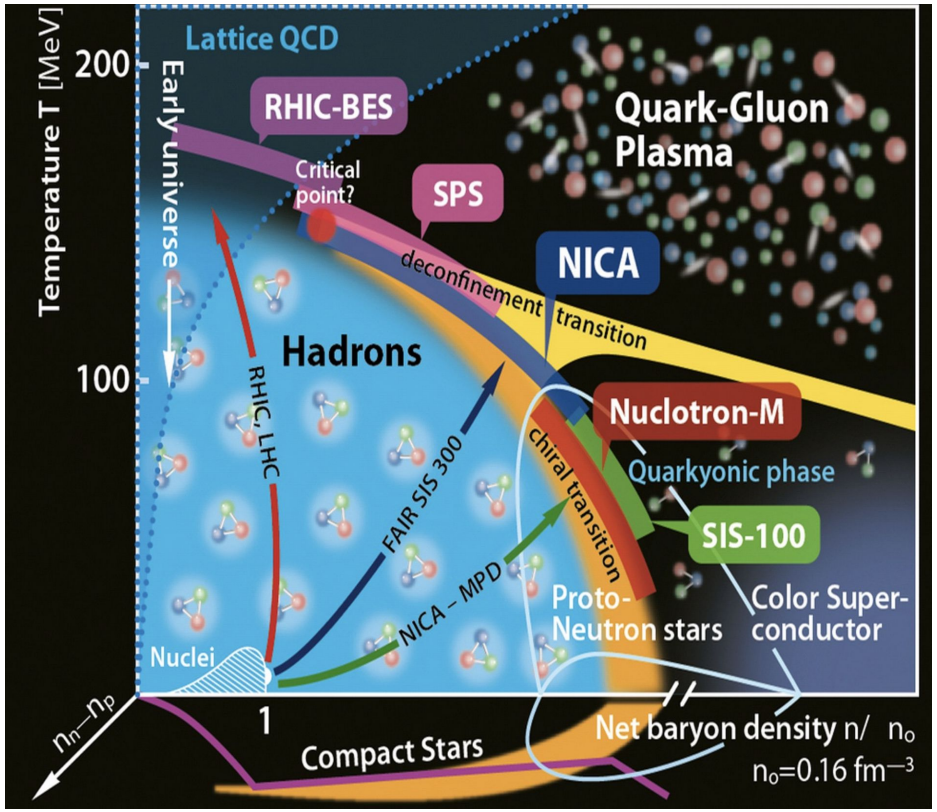
- Physics feasibility studies using centralized large-scale MC productions
- Centralized Analysis Framework for access and analysis of data Analysis Train:
  - consistent approaches and results across collaboration, easy storage and sharing of codes
  - reduced number of input/output operations for disks and databases, easier data storage on tapes
- Develop physics program, software and analysis infrastructure for real data analysis

Relativistic heavy-ion collisions



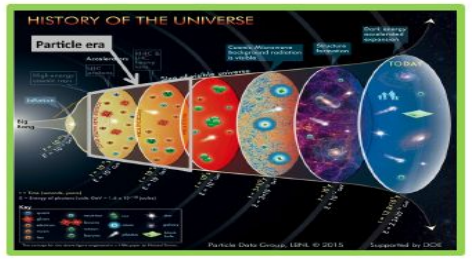
1970s-2000s – nuclear equation of state (EoS), search for the quark-gluon plasma (QGP)
2005s – QGP formation was observed at RHIC and it behaves as almost perfect liquid
2005-2010s – LQCD predicts crossover phase transition at top RHIC and LHC (high T, $\mu_B \approx 0$)

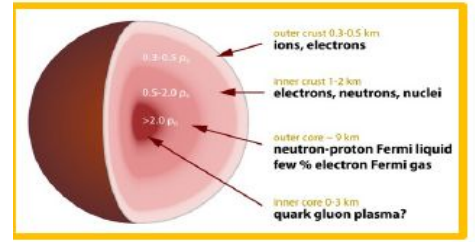
Since 2010s – Beam energy scans to study QCD phase diagram: search for the 1st order phase transition and CEP at Intermediate T, high μ_B



Relativistic heavy-ion collisions allows us to study QCD phase diagram

- **High beam energies ($\sqrt{s_{NN}}$>100 GeV):**
  - High T, $\mu_B \approx 0$
  - Evolution of the early Universe
- **Low beam energies (2.4<$\sqrt{s_{NN}}$<11 GeV):**
  - Intermediate T, high μ_B
  - Inner structure of the compact stars, neutron star mergers





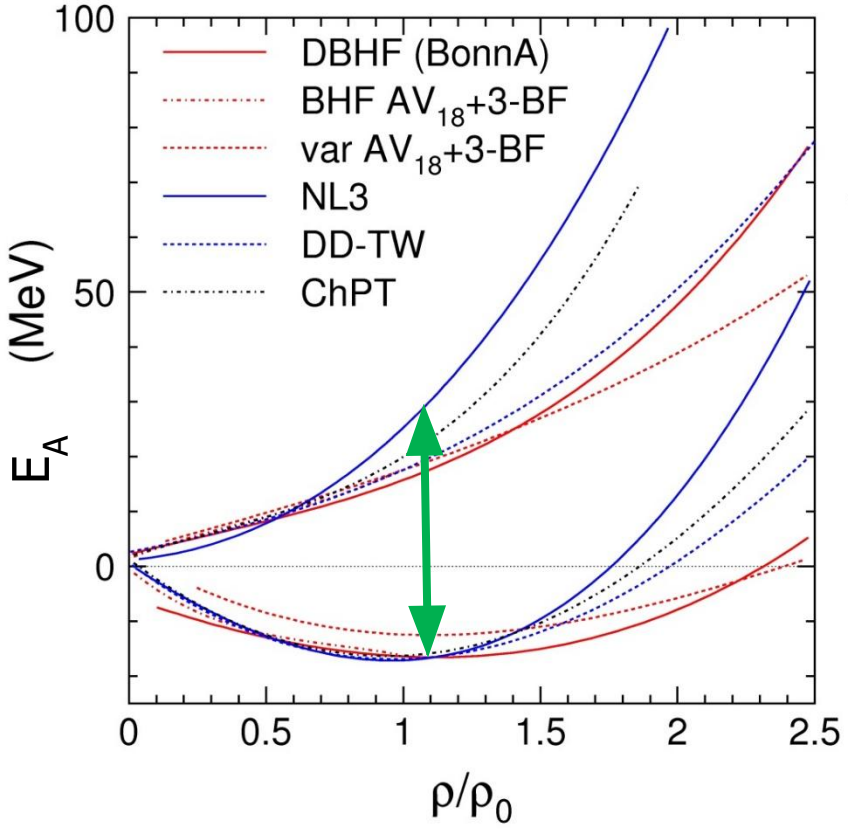
EOS for high baryon density matter

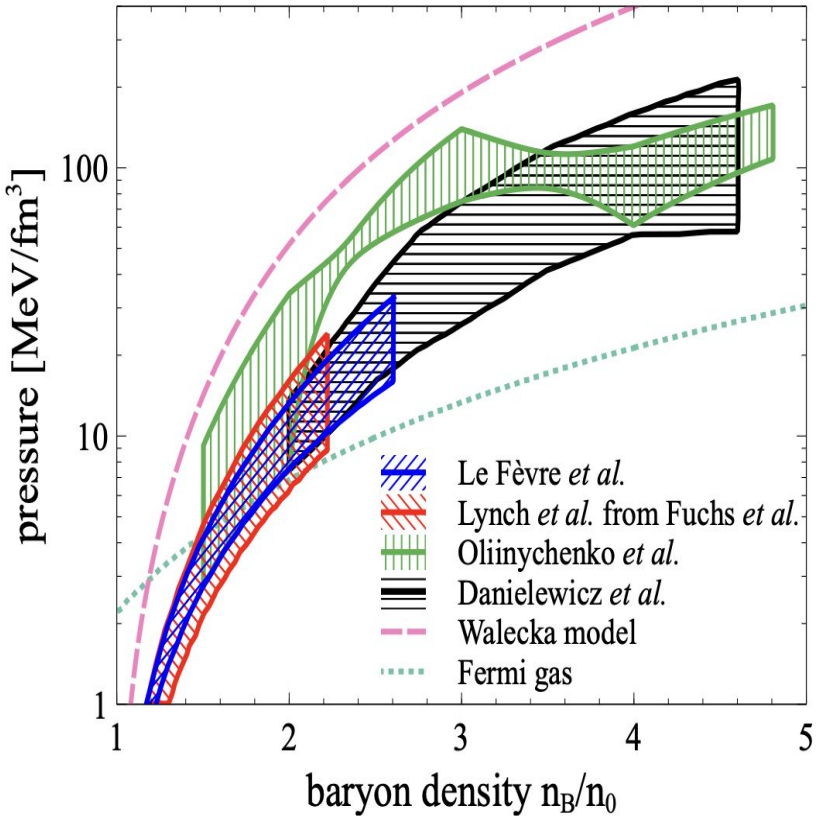
The binding energy per nucleon: $E_A(\rho,\delta) = E_A(\rho,0) + E_{sym}(\rho)\delta^2 + O(\delta^4)$

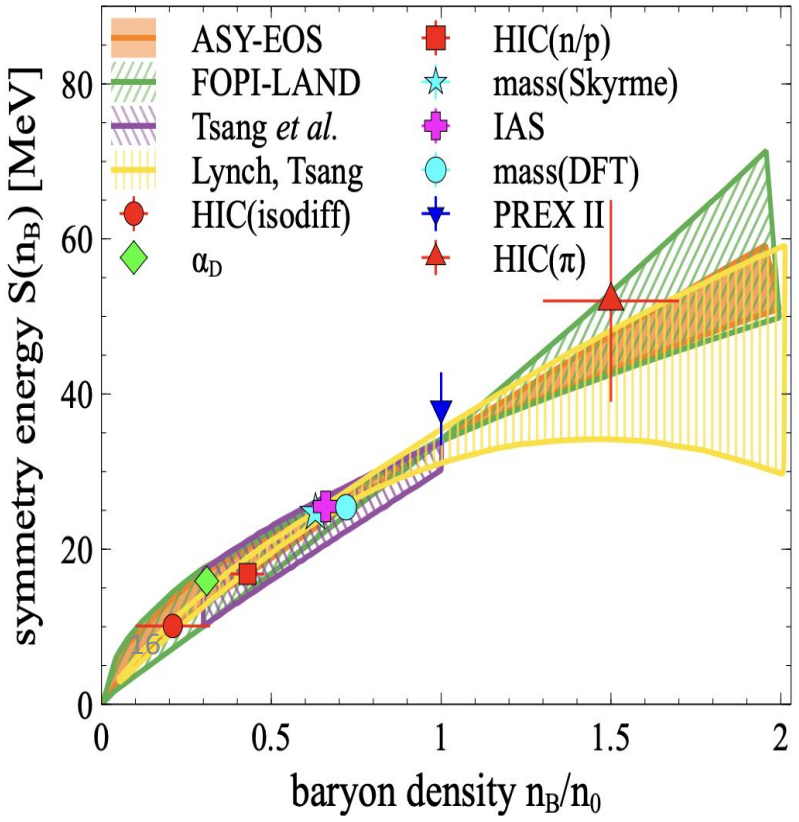
Isospin asymmetry: $\delta = (\rho_n - \rho_p)/\rho$

Symmetric matter

Symmetry energy





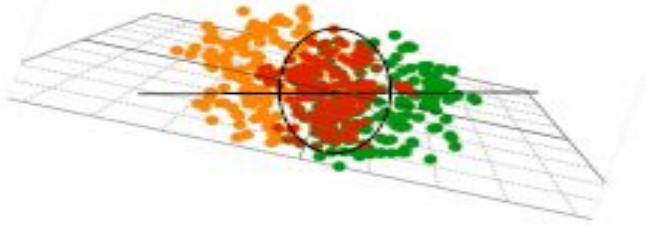


Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5

A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080

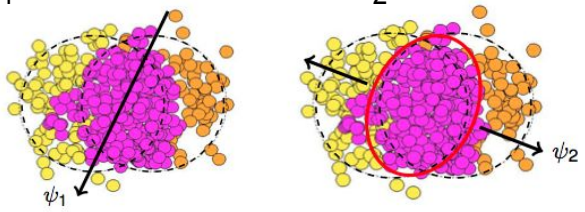
New data is needed to further constrain transport models with hadronic d.o.f.

Anisotropic flow



$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi \rangle + \langle r^n \sin n\phi \rangle}{\langle r^n \rangle}}$$

v_1 - directed flow; v_2 - elliptic flow;

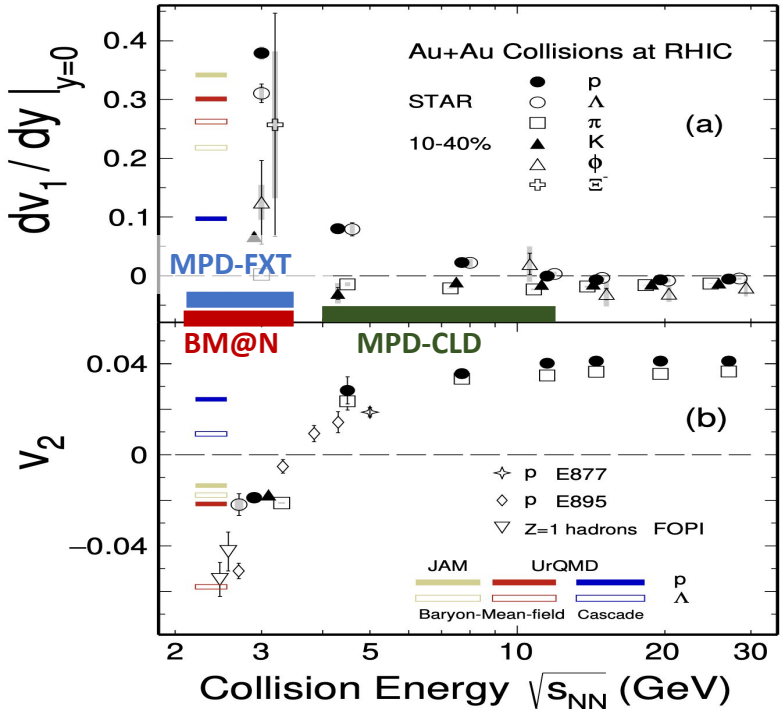


Phys.Rev.C 58 (1998) 1671-1678

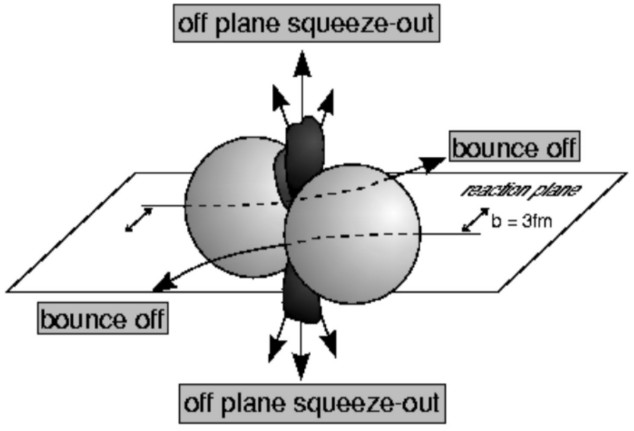
$$\frac{dN}{d\phi} \propto \left(1 + 2\sum_{n=1} v_n \cos\left[n\left(\phi - \Psi_n\right)\right]\right)$$

$$v_n = \langle \cos[n(\phi - \Psi_{RP})] \rangle$$

STAR, Phys.Lett.B 827 (2022) 137003



Initial eccentricity (and its attendant fluctuations) ϵ_n drive momentum anisotropy v_n with specific viscous modulation



At Nuclotron-NICA:

Strong energy dependence of dv_1/dy and v_2 at $\sqrt{s_{NN}}$=2-11 GeV

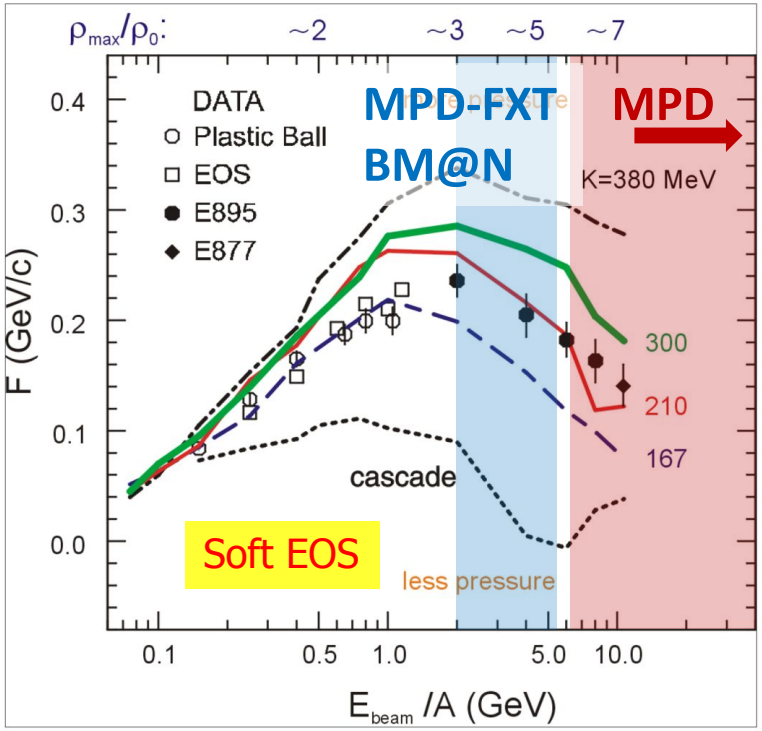
Anisotropic flow at Nuclotron-NICA energies is a delicate balance between:

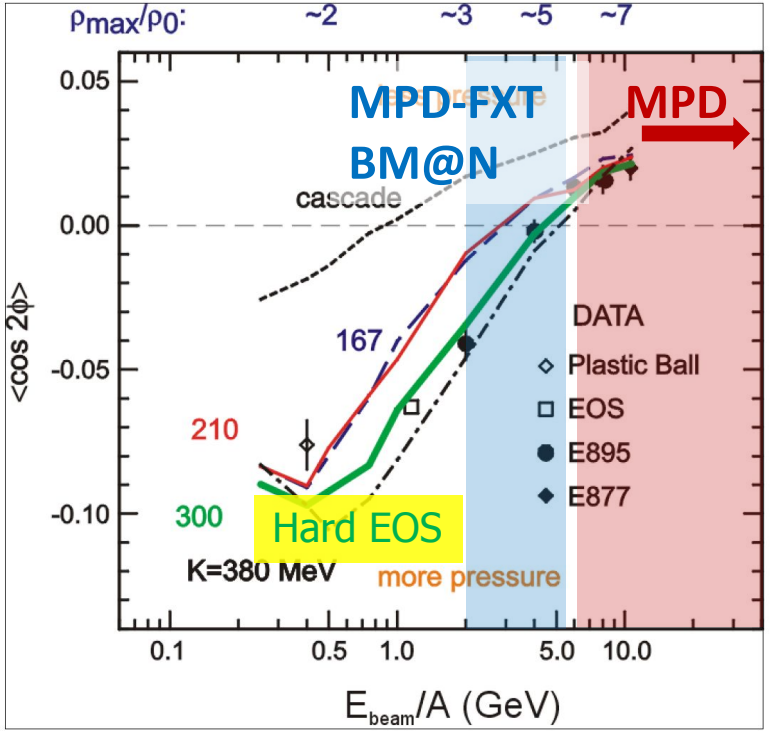
I. **The ability of pressure developed early in the reaction zone** $(t_{exp} = R/c_s)$

II. **The passage time for removal of the shadowing by spectators** $(t_{pass} = 2R/\gamma_{CM}\beta_{CM})$

Sensitivity of the anisotropic flow to the EOS

P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002)





$$F = \left.\frac{d\langle p_x/A\rangle}{d(y/y_{\mathrm{cm}})}\right|_{y/y_{\mathrm{cm}}=1}$$

$$v_2 \equiv \langle \cos(2(\varphi - \Psi_{RP})) \rangle$$

Anisotropic flow sensitive to the EoS

EoS extraction: define incompressibility

$$K_0 = 9\rho^2 \frac{\partial^2(E_A)}{\partial \rho^2}$$

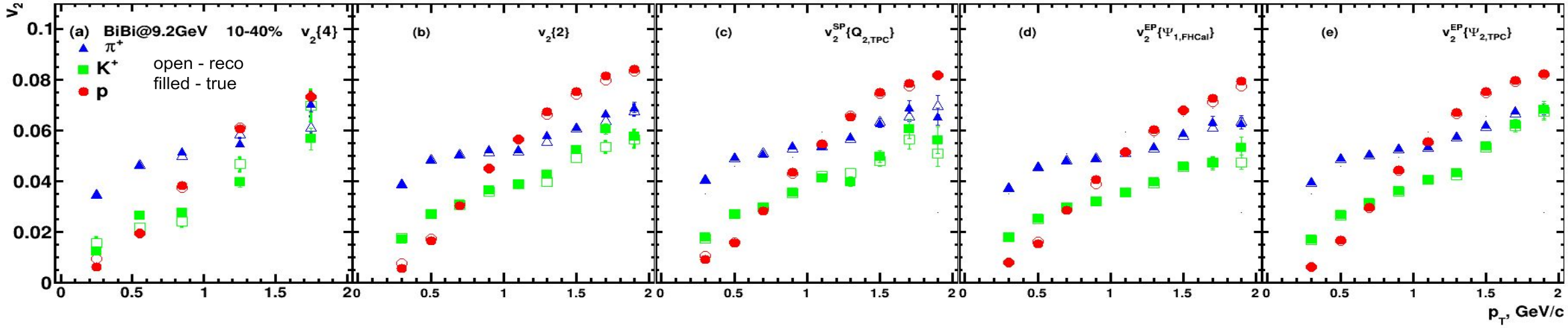
Discrepancy in the interpretation:

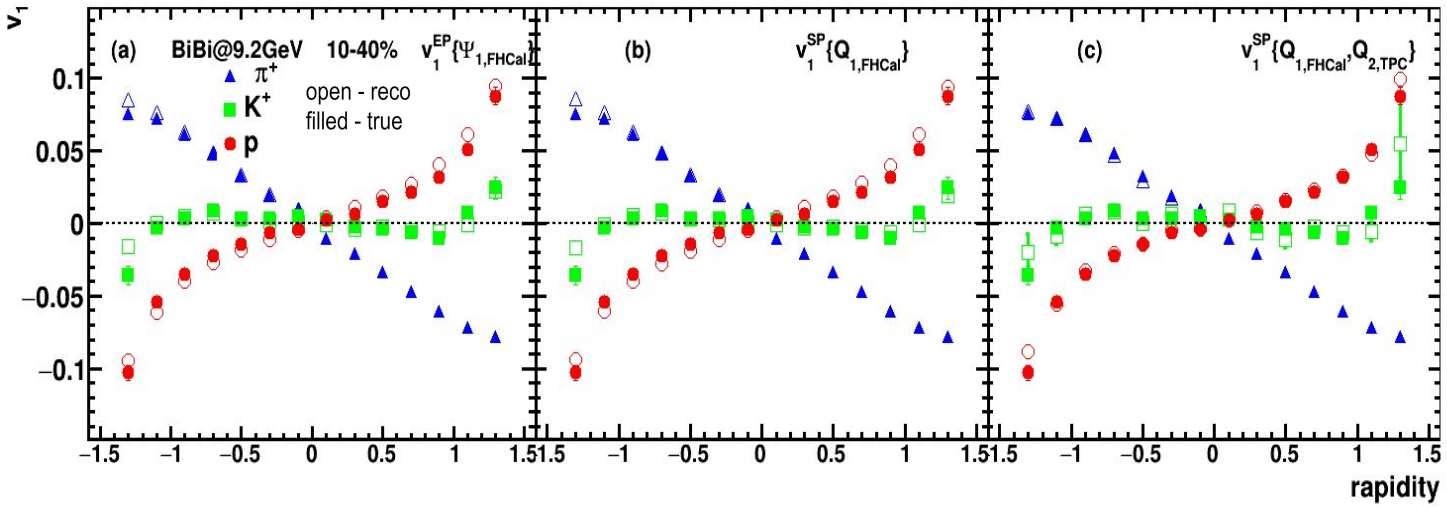
- v_1 suggests soft EoS (K_0≈210 MeV)
- v_2 suggests hard EoS (K_0≈380 MeV)

New measurements using new data and modern analysis techniques might address this discrepancy

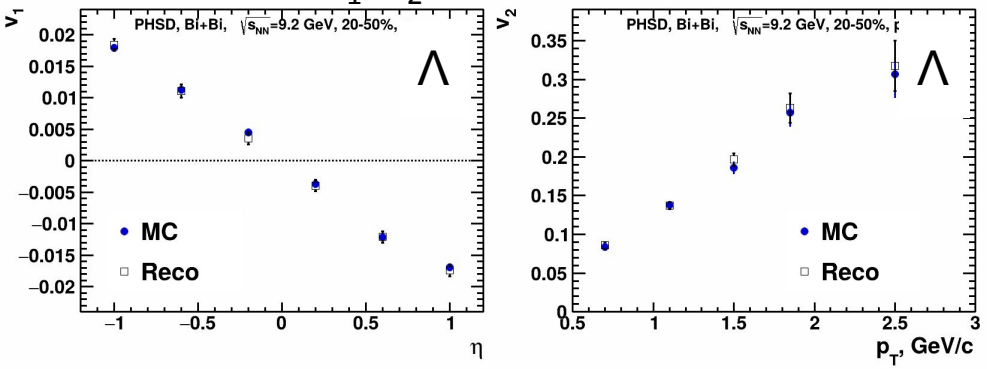
Additional measurements are essential to clarify the previous results

Anisotropic flow at MPD-CLD





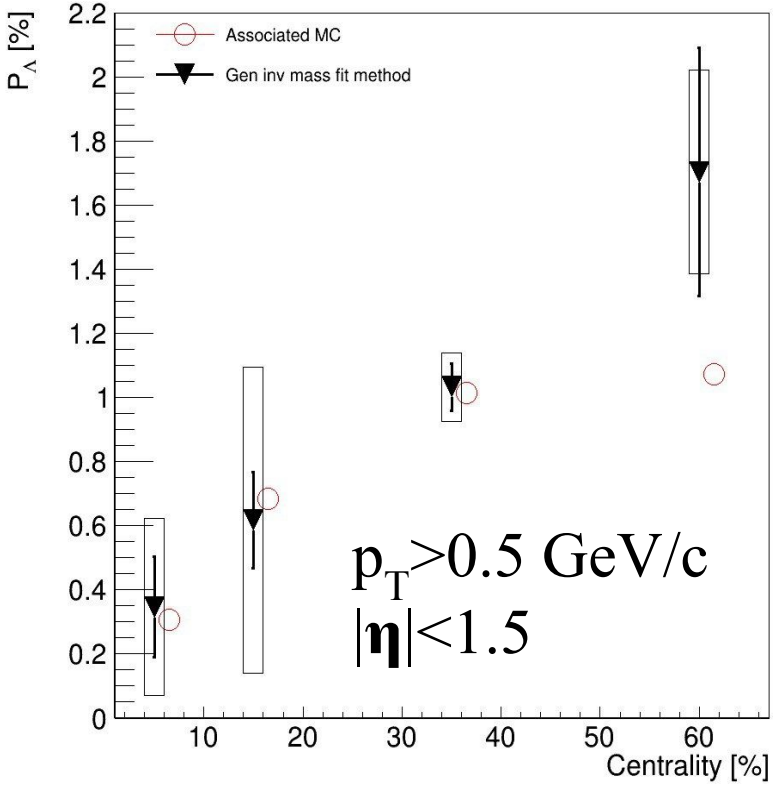
v_1, v_2 of V0 particles

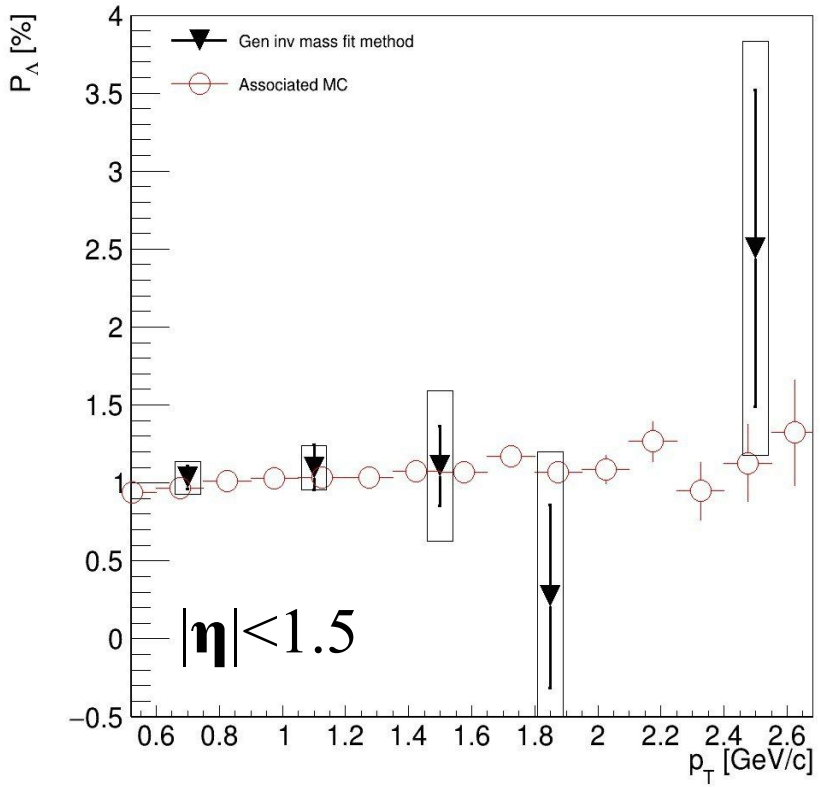


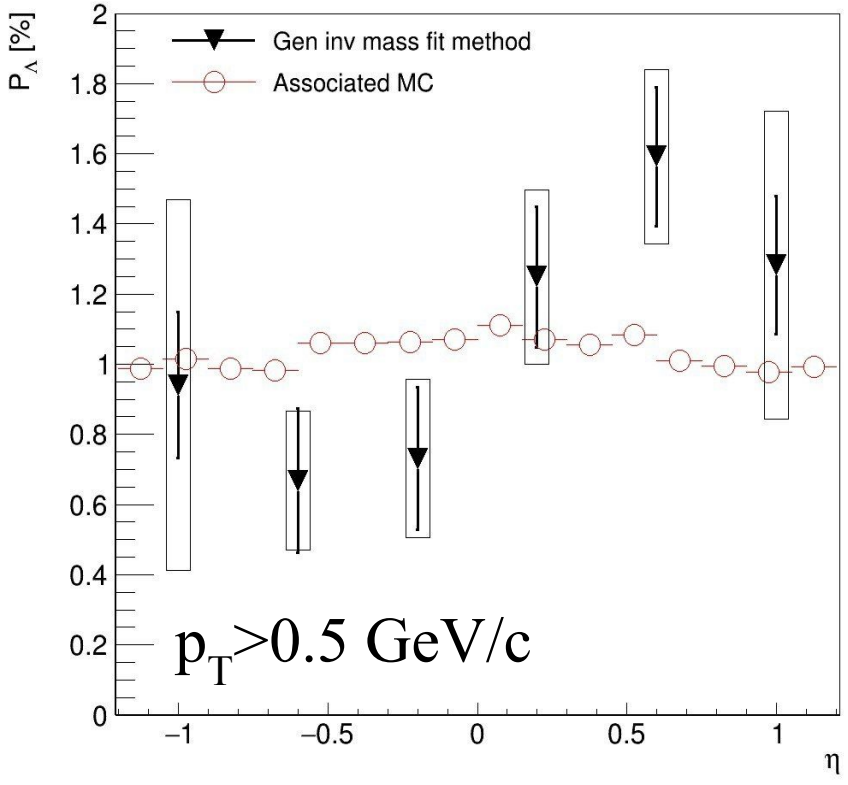
Good performance for flow measurements for all methods used (EP, SP, Q-cumulants)

Global polarization of Λ hyperon P_Λ

Eur.Phys.J.A 60 (2024) 4, 85







Good agreement with Associated MC

More statistics needed for differential (pT,**η**) measurements

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