Status and preparations for the first physics with the MPD experiment at NICA

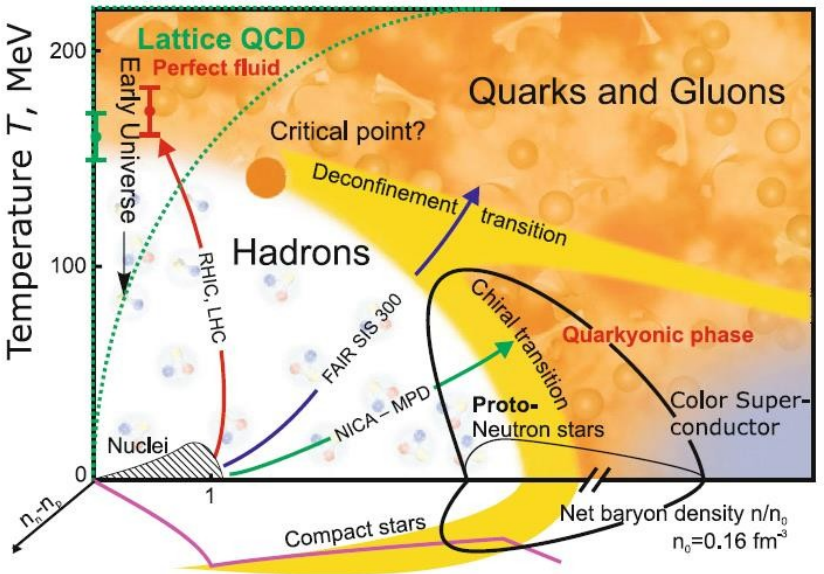
Oleg Golosov (NRC “Kurchatov Institute”, NRNU MEPhI)
for the MPD Collaboration

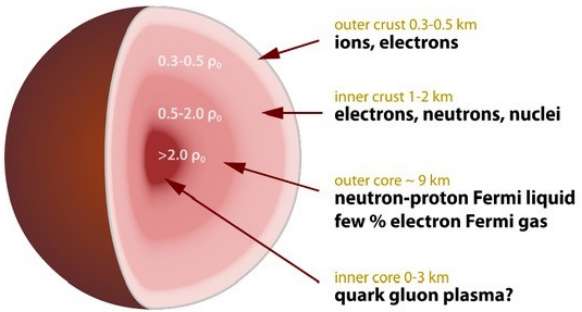
The work has been supported by the Ministry of Science and Higher Education of the Russian Federation,
Project "Fundamental and applied research at the NICA megascience experimental complex"
№ FSWU-2024-0024

NUCLEUS 2024, Dubna

Relativistic heavy-ion collisions

- At $\mu_B \sim 0$, smooth crossover (lattice QCD calculations + data)
- At large μ_B, 1st order phase transition is expected starting from QCD critical point
- BM@N and MPD will study QCD medium at extreme net baryon densities
- Several ongoing (NA61/SHINE, STAR) and future experiments (CBM) cover the same energy range





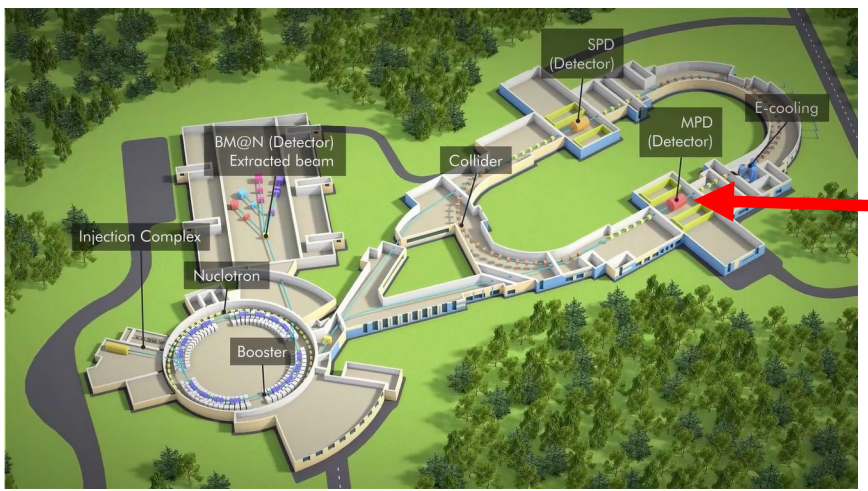
High baryon densities →
→ inner structure of compact stars

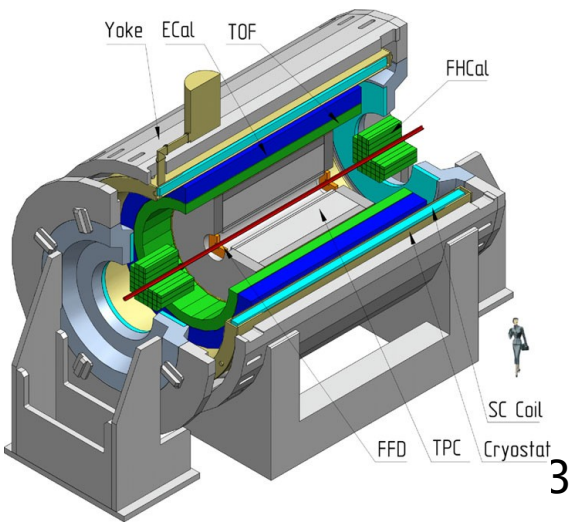
MPD at NICA

One of the two experiments at NICA collider to study heavy-ion collisions at $\sqrt{s_{NN}}$ = 4−11 GeV

Main subsystems:

- **TPC** (|Δφ| < 2π, |η| ≤ 1.6): charged particle tracking + momentum reconstruction + dE/dx identification
- **TOF** (|Δφ| < 2π, |η| ≤ 1.6): charged particle identification
- **EMC** (|Δφ| < 2π, 2.9 < |η| < 3.3): energy and PID for ɣ/$e^{\pm}$ + charged particle identification (limited ability)
- **FHCal** (|Δφ| < 2π, 2 < |η| < 5) and **FFD** (|Δφ| < 2π, 2.9 < |η| < 3.3): event triggering, event geometry, T_0
- **ITS**: secondary vertex reconstruction for heavy-flavor decays (considered for later runs)





MPD subsystems status

Magnet and cryogenics

Cooling and field measurements in Sept 2024

TPC – main tracker

Assembly to be finished in Nov 2024

Support structure

Ready for installation

MPD subsystems status

TOF

Ready for installation

ECAL

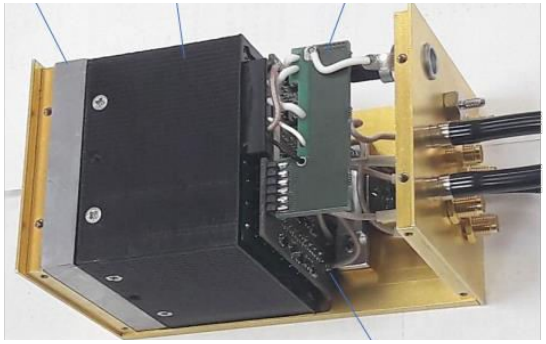
80% of modules

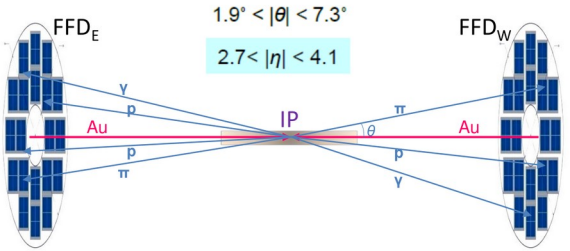
ready in Nov 2024

FHCal

Ready for installation

FFD



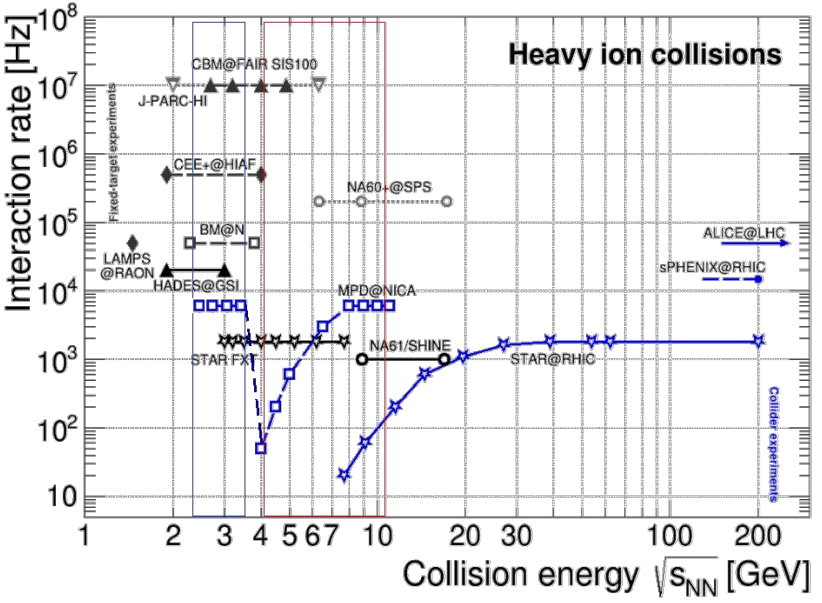


Ready for installation

Beams and operation modes

First beams (end of 2025):

- Bi+Bi/ Xe+Xe at $\sqrt{s_{NN}} \leq 7$ GeV
- Not optimal beam optics resulting in wide z-vertex distribution ($\sigma_z \sim 50$ cm)

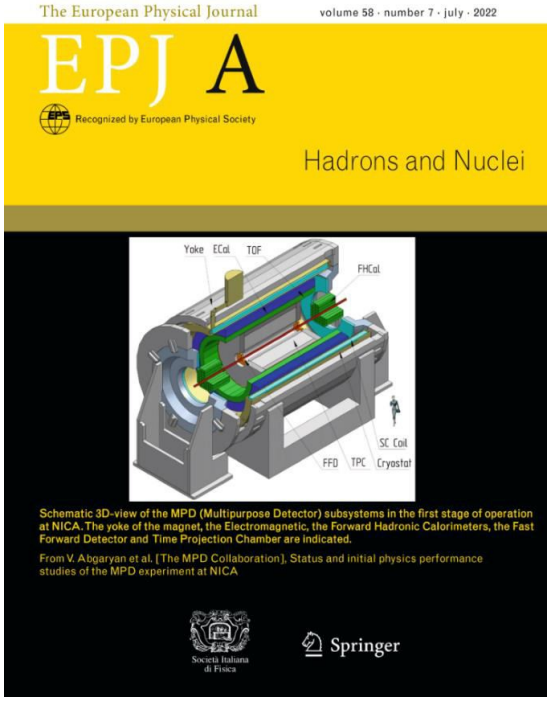


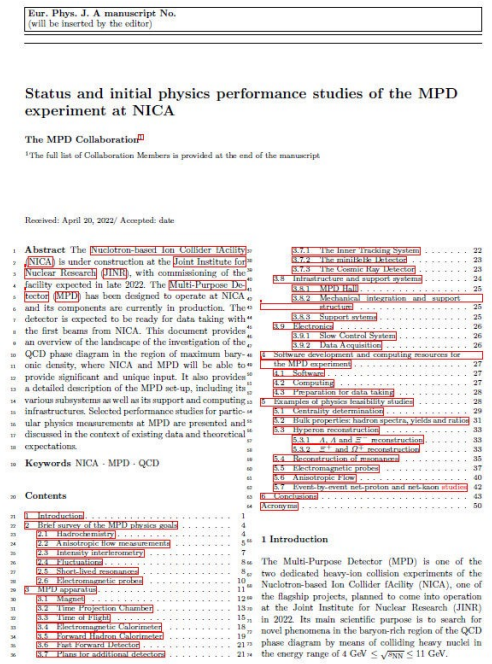
Operation modes:

- Collider
- Fixed-target (one beam and ~100 μm wire close to the edge of the central barrel)
  - extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N and CBM)
  - increases event rate at lower collision energies (~ 50 Hz at $\sqrt{s_{NN}}$ = 4 GeV at design luminosity)
  - backup start-up solution (too low luminosity, only one beam, etc.)

Collaboration activity

- Over 200 publications in total for hardware, software and physics studies (SPIRES)
- Presentations at all major conferences in the field
- First collaboration paper on MPD status and phyics performance published in 2022: Eur.Phys.J.A 58 (2022) 7, 140
- The second paper is in preparation.





MPD physics capabilities

Global observables

- Total event multiplicity and energy
- Total cross-section measurement
- Centrality determination
- Event plane measurement at diff. rapidities
- Spectator measurement

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 Diagram

Correlations and Fluctuations

- Collective flow of hadrons
- Vorticity, polarization
- E-by-E fluctuations of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

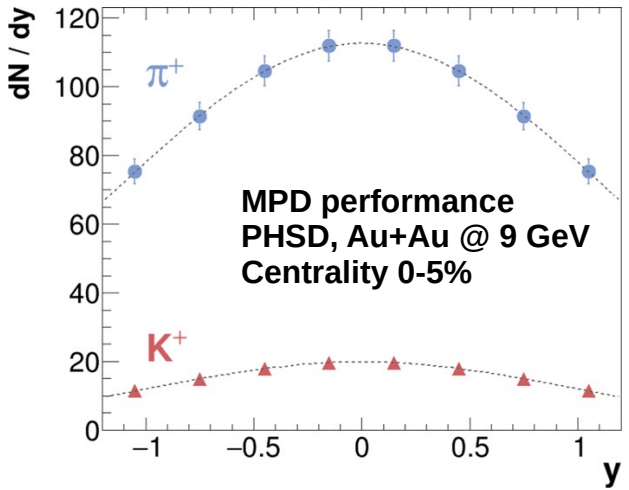
Electromagnetic probes

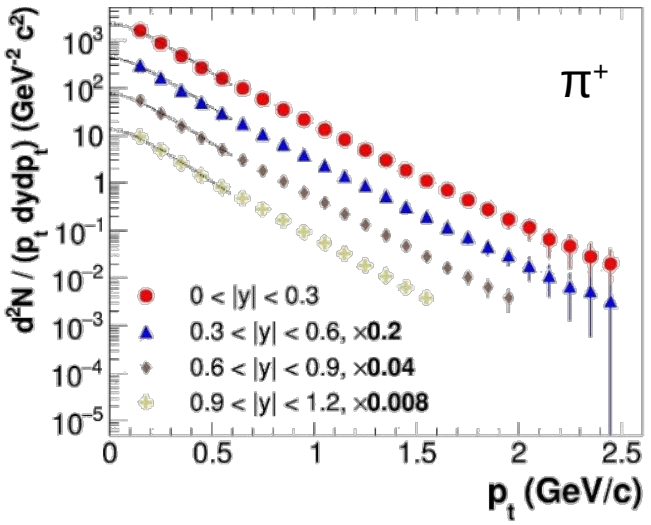
- Electromagnetic calorimeter measurements
- Photons in ECAL and central barrel
- Low mass dilepton spectra, in-medium modification of resonances and intermediate mass region

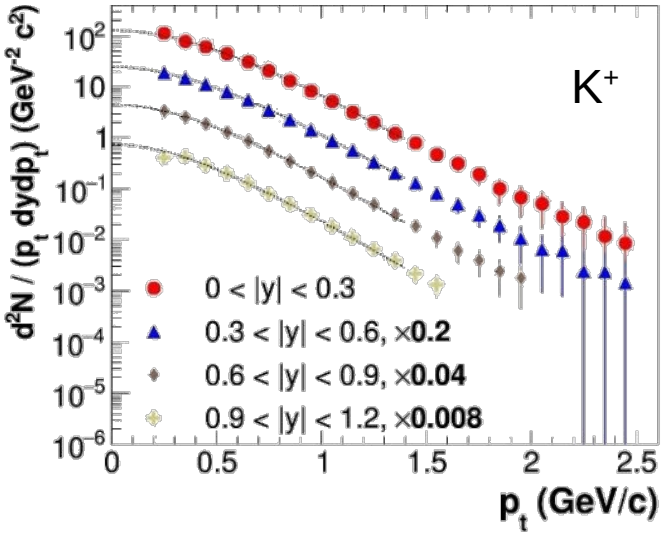
Heavy flavor

- 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

MPD performance: charged hadron production



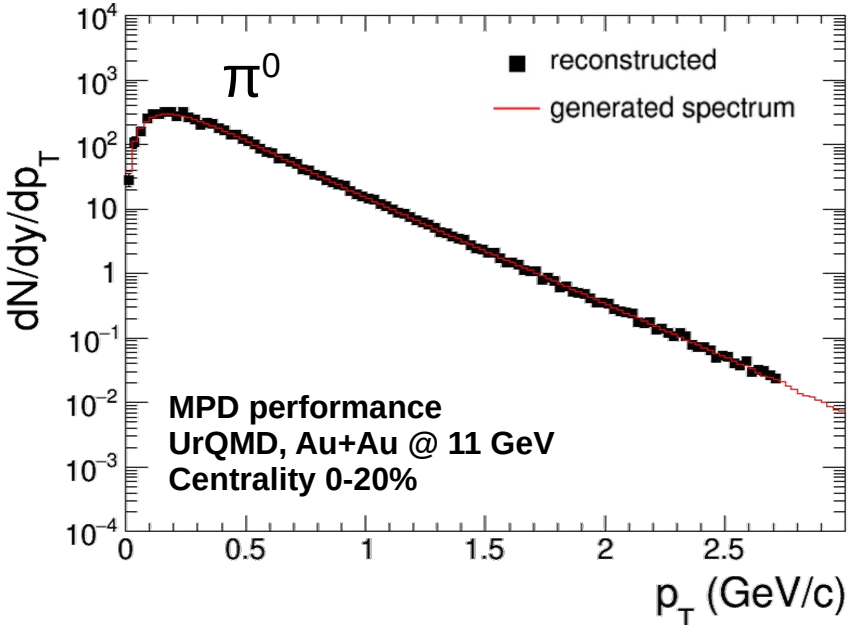


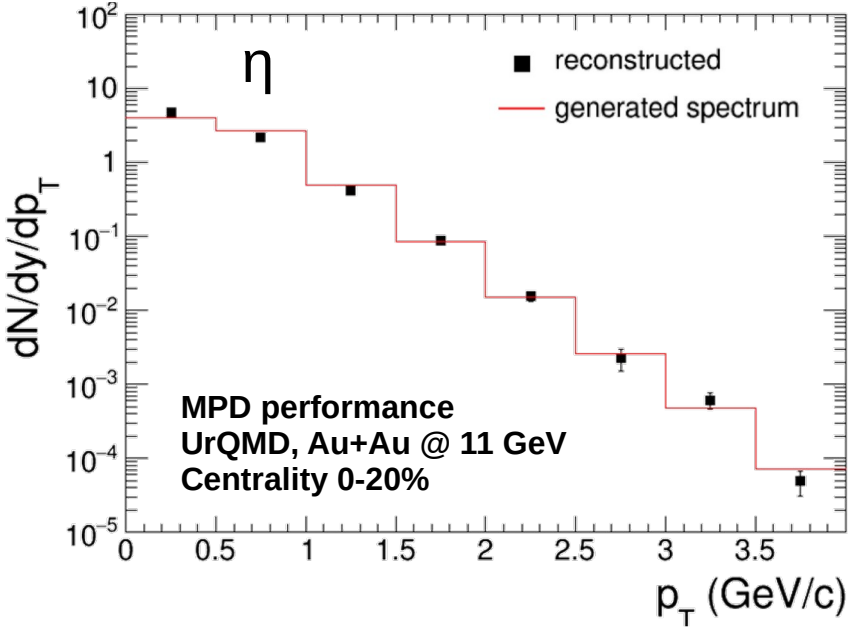


Phys.Part.Nucl. 53 (2022) 2, 203-206

- Probe freeze-out conditions, collective expansion, hadronization mechanisms, strangeness production (“horn” for K/p), parton energy loss, etc. with particles of different masses, quark contents/counts.
- Charged hadrons: large (~ 70% the π/K/p production) and uniform acceptance + excellent PID capabilities of TPC and TOF down to p_T ~ 0.1 GeV/c

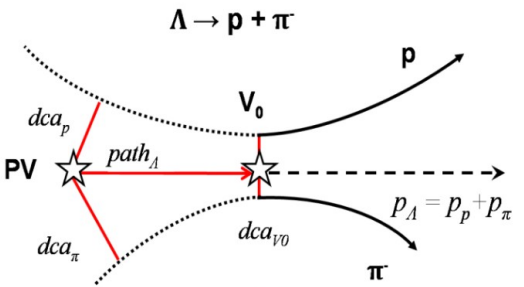
MPD performance: neutral hadron production



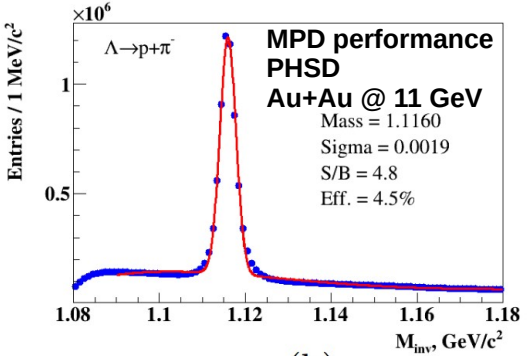


- MPD will be able to measure differential production spectra, integrated yields and $\langle p_T \rangle$, particle ratios, multiplicity distributions for a variety of identified hadrons (π, K, η, ω, p, η')
- Neutral mesons (π^0, η, K_s, ω, η'): ECAL reconstruction + photon conversion method (PCM)
- Help to extend extend p_T ranges of charged particle measurements and assess systematics

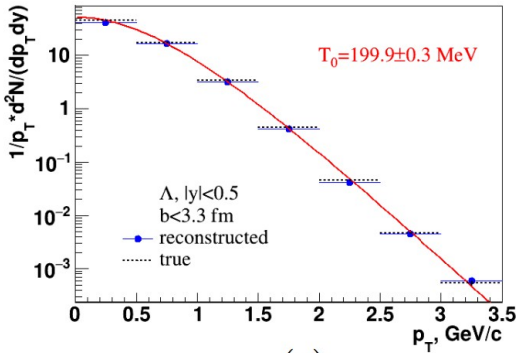
MPD performance: hyperon production



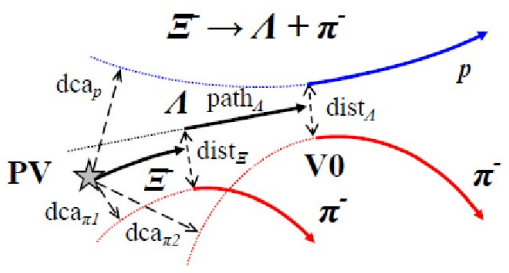
(a)

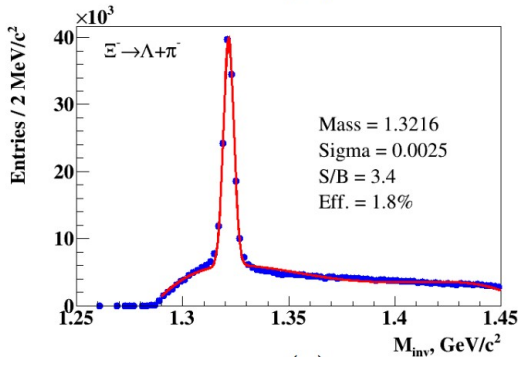


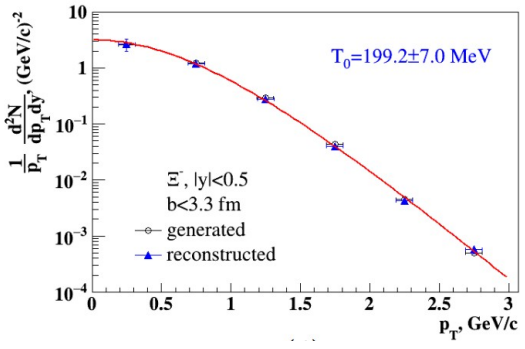
(b)



(c)



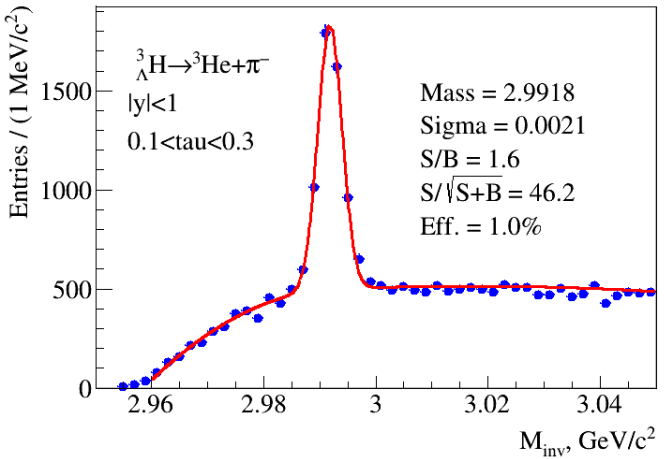


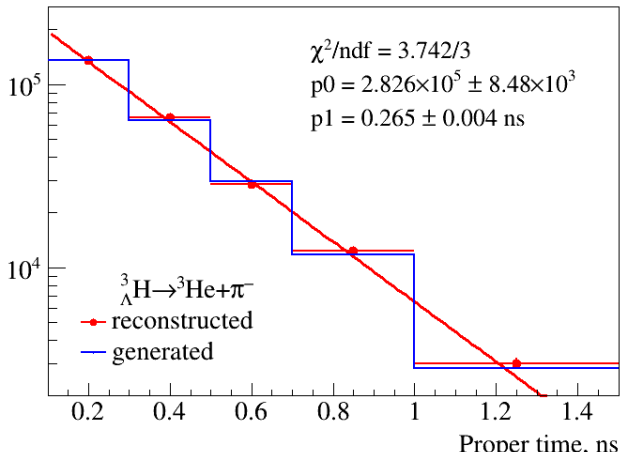


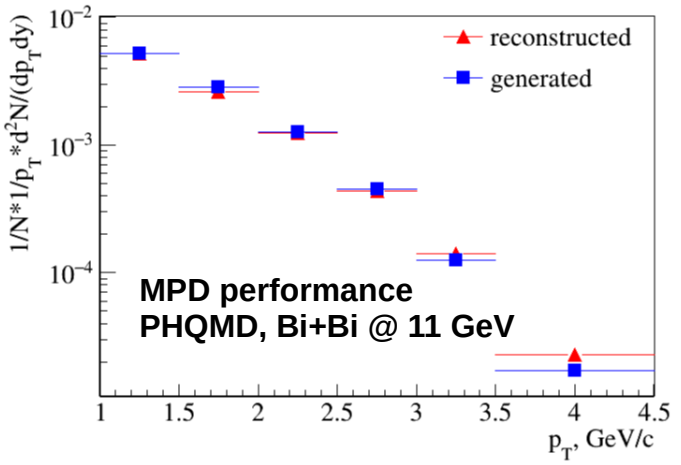
Acta Phys. Pol. B Proc. Suppl. 14, 529 (2021)

- Strangeness enhancement is considered as a signature of the QGP formation with no consensus on the dominant strangeness enhancement mechanisms – precise measurements needed in pp, pA and AA
- Strange baryons can be reconstructed with good S/B ratios using charged hadron identification in the TPC and TOF and different decay topology selections

MPD performance: hypernuclei production





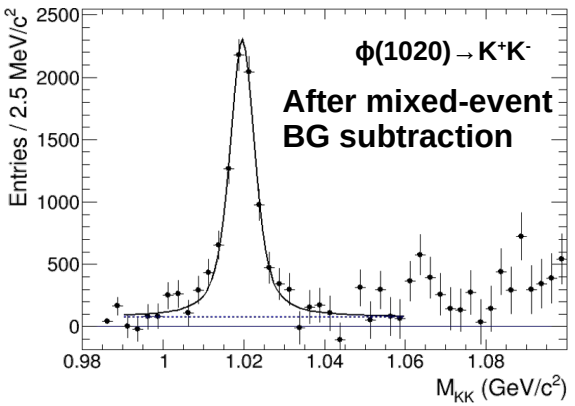


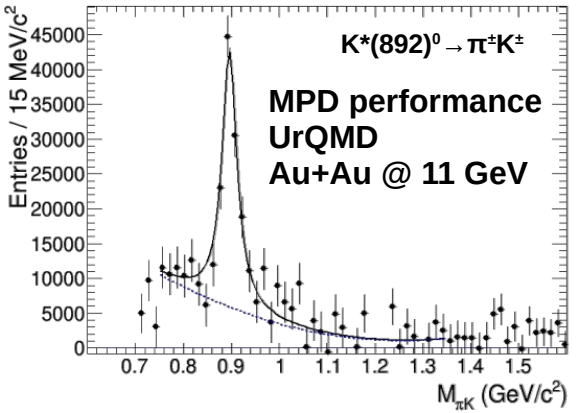
Physics 2023, 5(2), 391-397

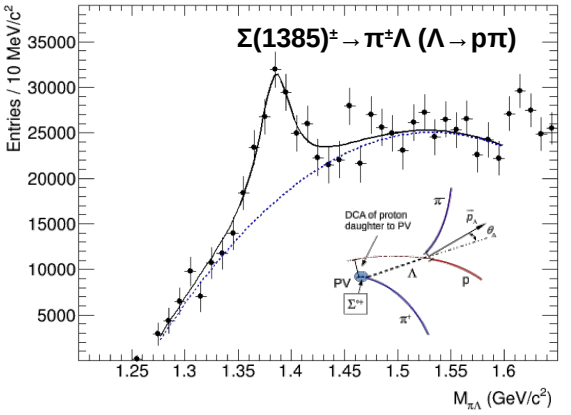
$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right)$$

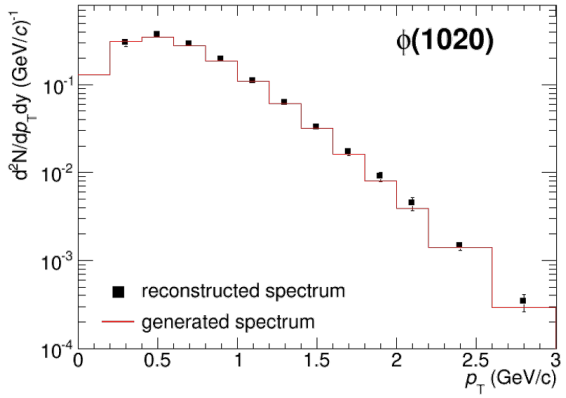
- Hypernuclei measurements may shed light on their production mechanism (statistical hadronization (SHM) or coalescence).
- Statistical models predict enhanced hypernuclear production at NICA energies → even double hypernuclei are reachable.
- Generator yields and lifetimes of hypernuclei are well reproduced in MPD performance studies with 40M events for $^3_\Lambda$H.

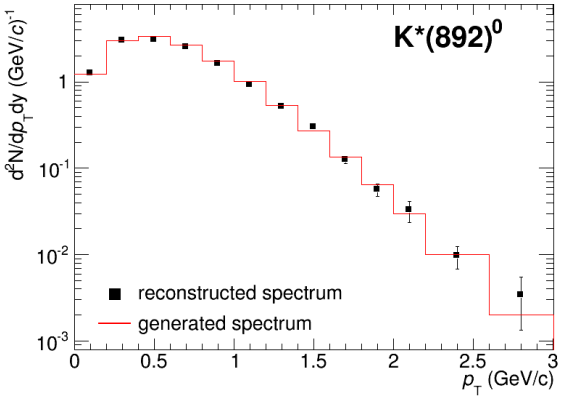
MPD performance: resonance production

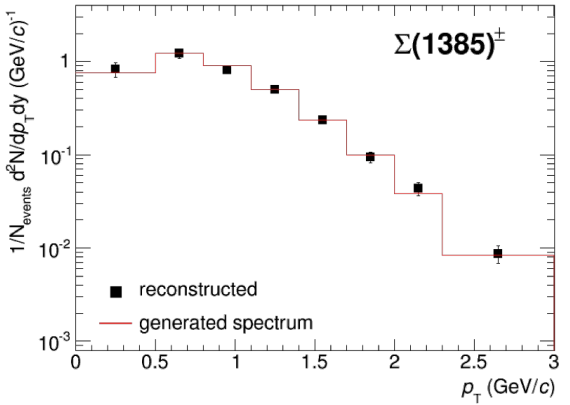








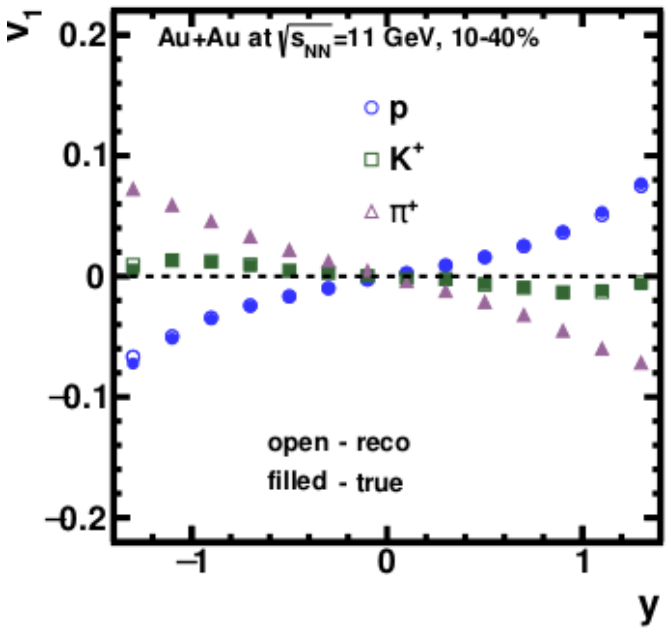


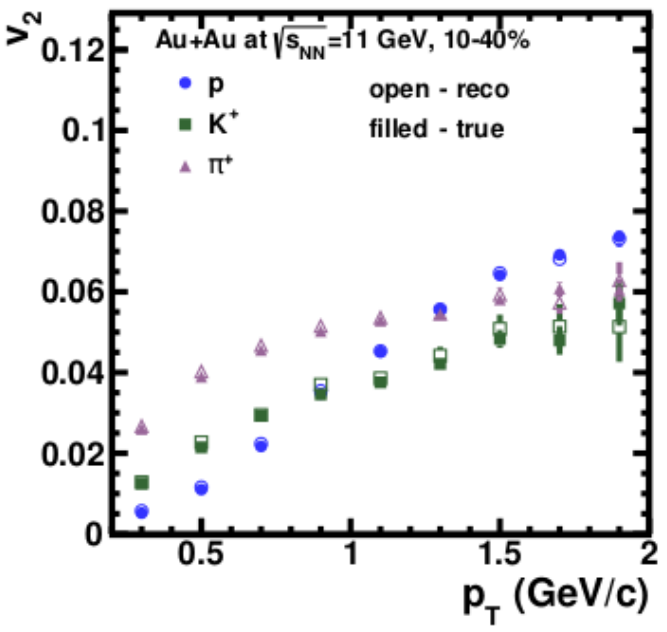


Phys.Scripta 96 (2021) 6, 064002

MPD is capable of resonance reconstruction using TPC and TOF identification + selection based on weak decay topology. First measurements are feasible with 10M events.

MPD performance: anisotropic flow



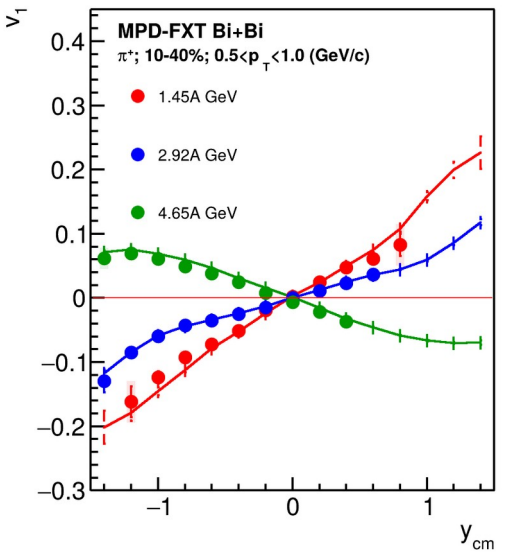


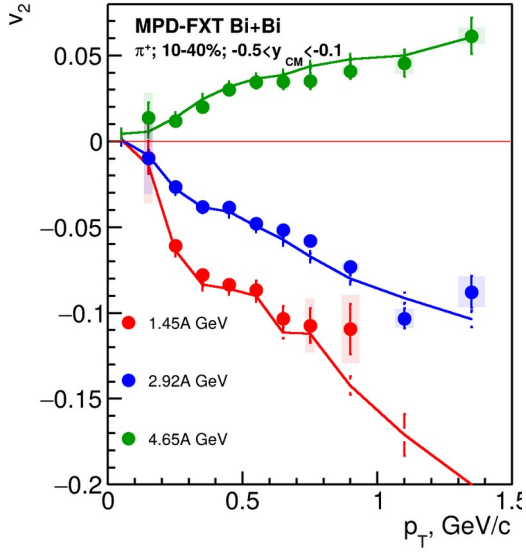
Phys.Part.Nucl. 52 (2021) 4, 618-623

- Anisotropic flow helps constrain transport and compresibility parameters of the matter produced in heavy ion collisions
- Precise reconstruction of directed (v_1) and elliptic (v_2) flow should be possible with MPD for p, $\pi^{\pm}$, $K^{\pm}$. Several methods tested to provide systematics.

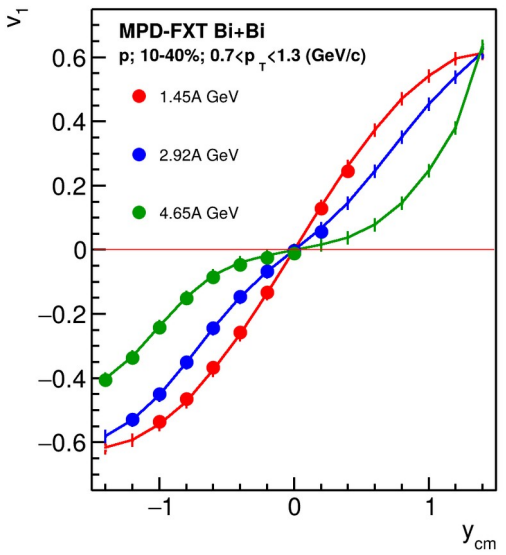
MPD performance: anisotropic flow in FXT mode

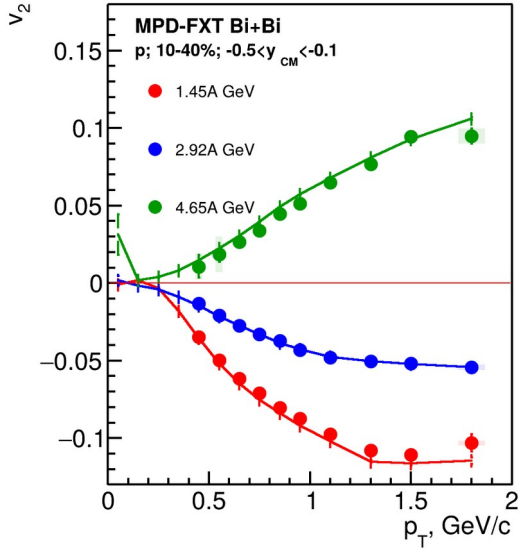
pion





proton

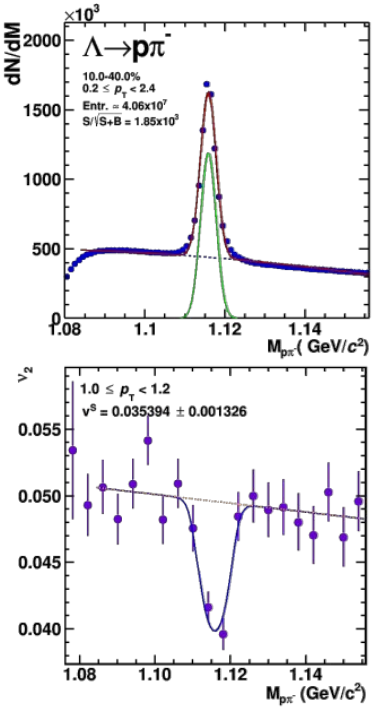


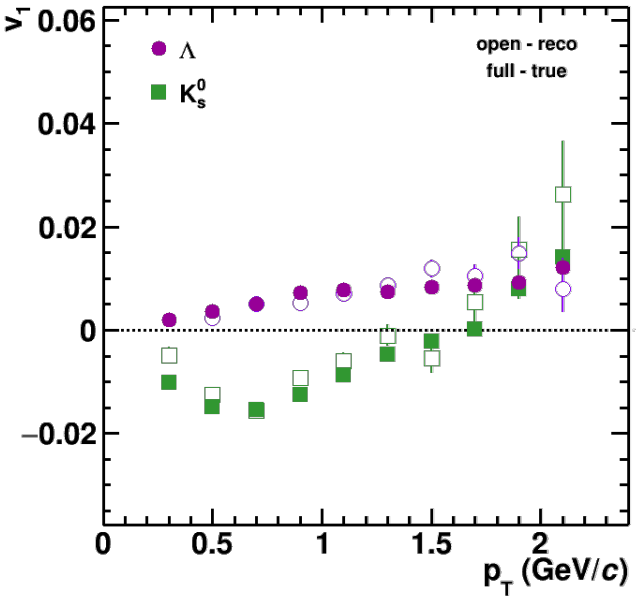


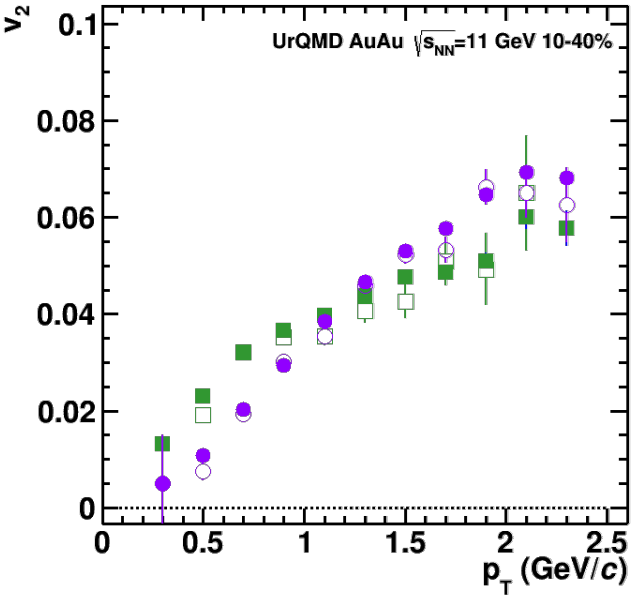
- Good performance of MPD in FXT mode for reconstruction of directed and elliptic flow of protons and charged pions with acceptable coverage of midrapidity.

[See talk by P. Parfenov]

MPD performance: anisotropic flow of V0



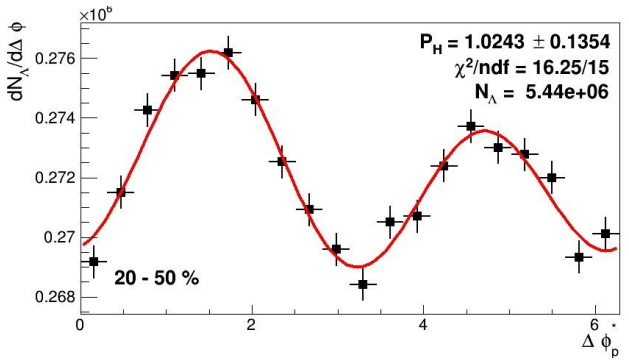




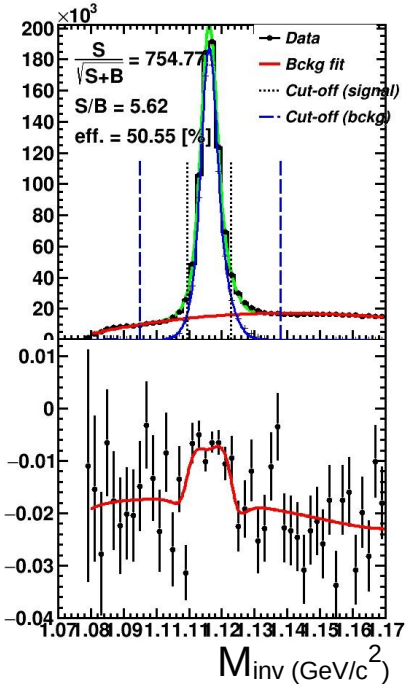
Phys.Part.Nucl. 52 (2021) 4, 618-623

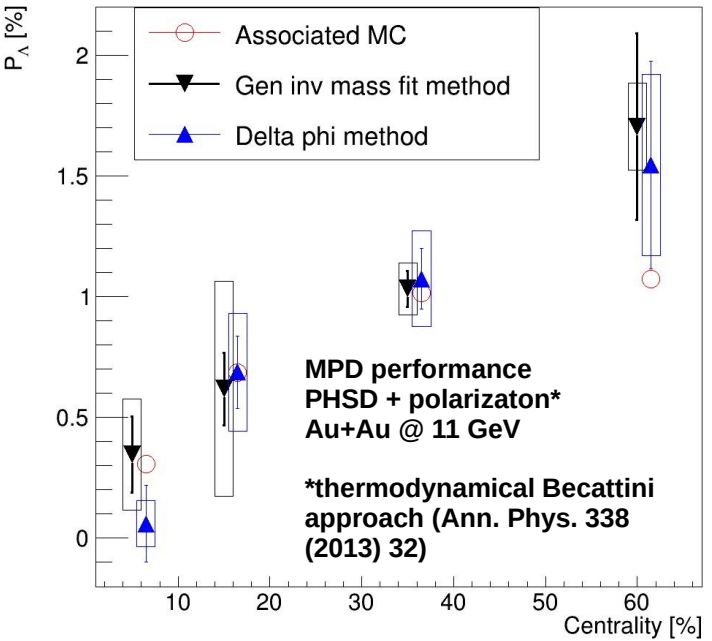
- Differential flow signal extraction using invariant mass fit method
- Reasonable agreement between reconstructed and generated v_n signals for Λ and K^0_S.
- Similar measurements are posible for other weakly decaying hyperons and short-lived resonances.

MPD performance: global polarization



$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha}\frac{1}{R^1_{\mathrm{EP}}}\left\langle \sin(\Psi^1_{\mathrm{EP}} - \phi^*)\right\rangle$$



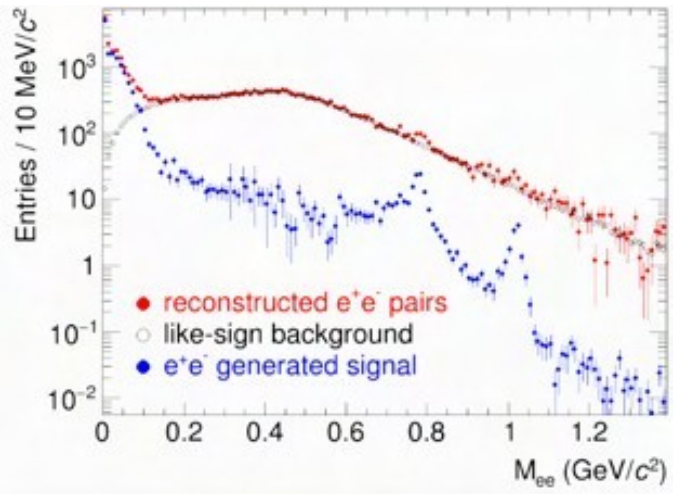


- Large angular momentum and strong magnetic field are formed in mid-central collisions → Vorticity to the QGP and polarization of particles in the final state.
- Invariant mass fit and Δφ methods tested. Measurement for $\Lambda/\bar{\Lambda}$ should be feasible with 15M events.

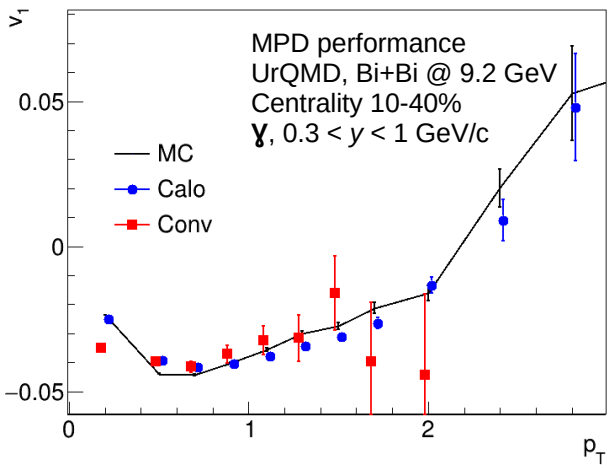
See poster by V. Troshin

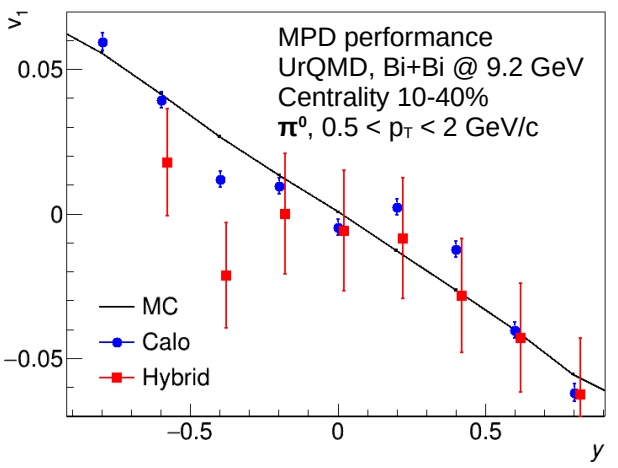
MPD performance: in progress

Dielectron measurements



Flow of inclusive photons, π^0 and η mesons → → direct photon measurements





Summary and outlook

- 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 the first physics paper was published. Second paper under preparation.
- 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
- First operations of the MPD detector are expected at the end of 2025
- Start of data taking at fixed target mode

Thanks for your attention

The work has been supported by the Ministry of Science and Higher Education of the Russian Federation, Project "Fundamental and applied research at the NICA megascience experimental complex" № FSWU-2024-0024