



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

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for the MPD Collaboration

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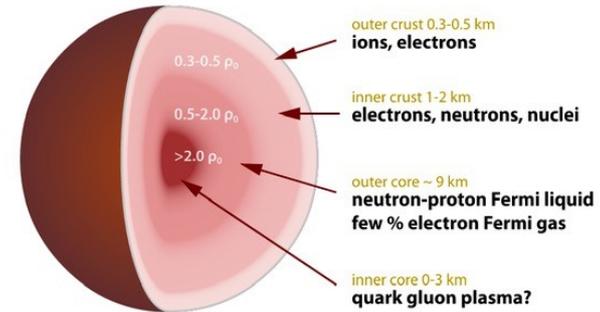
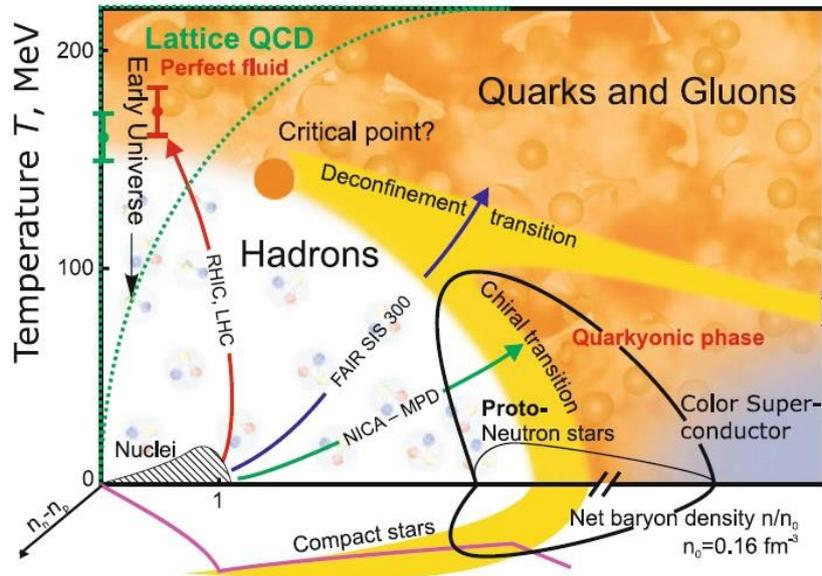


NUCLEUS 2024, Dubna



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



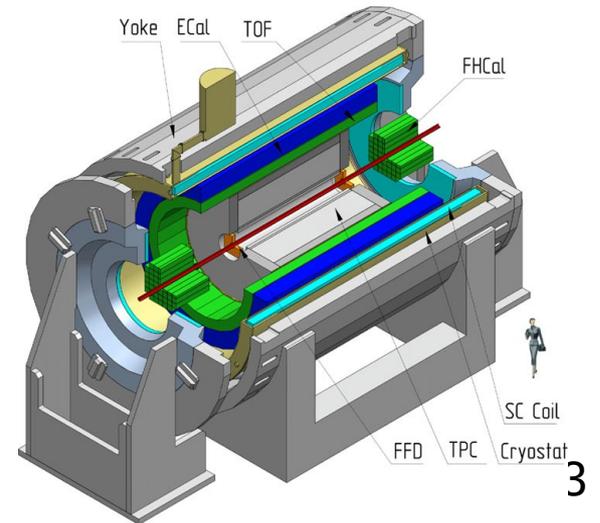
High baryon densities \rightarrow
 \rightarrow inner structure of compact stars

MPD at NICA

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

Main subsystems:

- **TPC** ($|\Delta\phi| < 2\pi$, $|\eta| \leq 1.6$): charged particle tracking + momentum reconstruction + dE/dx identification
- **TOF** ($|\Delta\phi| < 2\pi$, $|\eta| \leq 1.6$): charged particle identification
- **EMC** ($|\Delta\phi| < 2\pi$, $2.9 < |\eta| < 3.3$): energy and PID for γ/e^\pm + charged particle identification (limited ability)
- **FHCal** ($|\Delta\phi| < 2\pi$, $2 < |\eta| < 5$) and **FFD** ($|\Delta\phi| < 2\pi$, $2.9 < |\eta| < 3.3$): 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



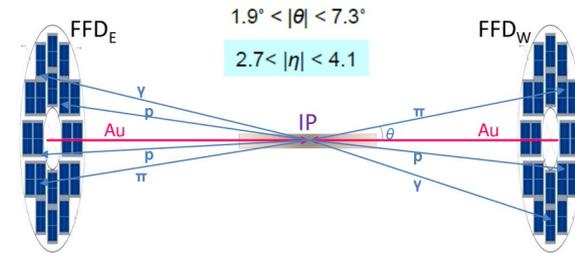
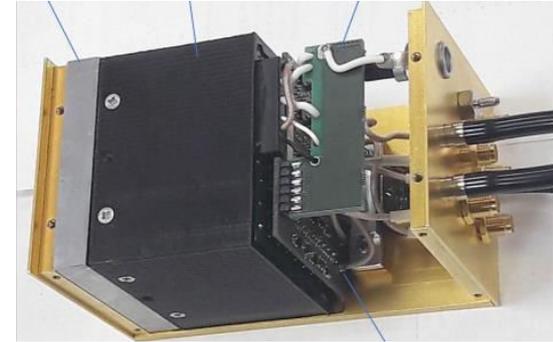
80% of modules
ready in Nov 2024

FHCAL



Ready for installation

FFD



Ready for installation

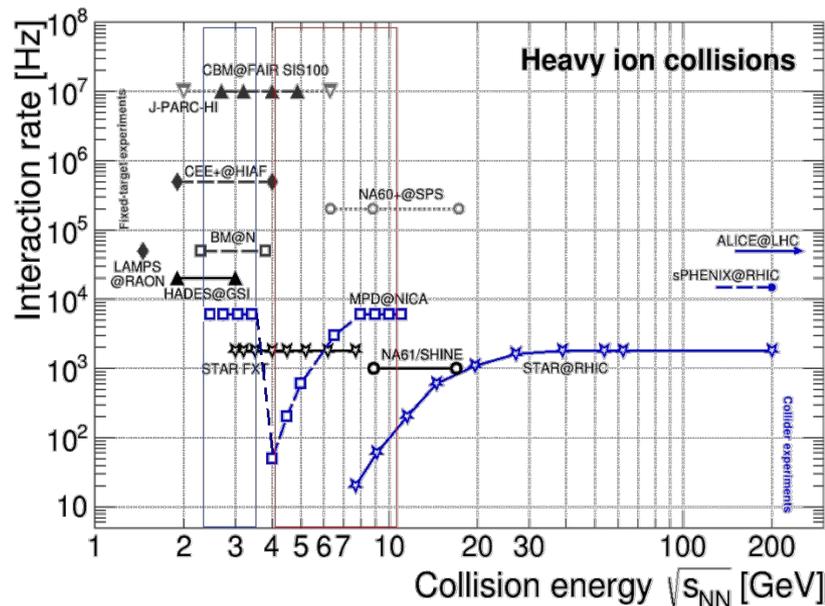
Beams and operation modes

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)

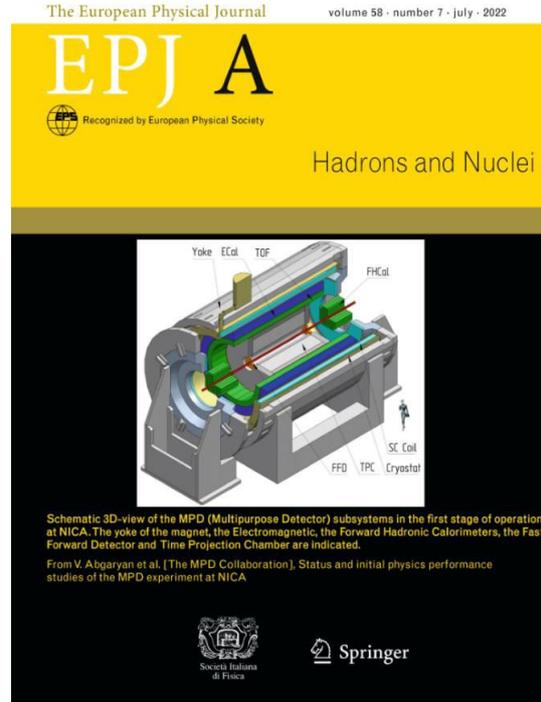
Operation modes:

- Collider
- Fixed-target (one beam and ~ 100 μm wire close to the edge of the central barrel)
 - extends energy range of MPD to $\sqrt{s_{NN}} = 2.4\text{-}3.5$ 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 physics performance published in 2022: Eur.Phys.J.A 58 (2022) 7, 140
- The second paper is in preparation.



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 Collaboration¹

¹The full list of Collaboration Members is provided at the end of the manuscript.

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1 Introduction

The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nucleon-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 $4 \text{ GeV} \leq \sqrt{s_{NN}} \leq 11 \text{ GeV}$.

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

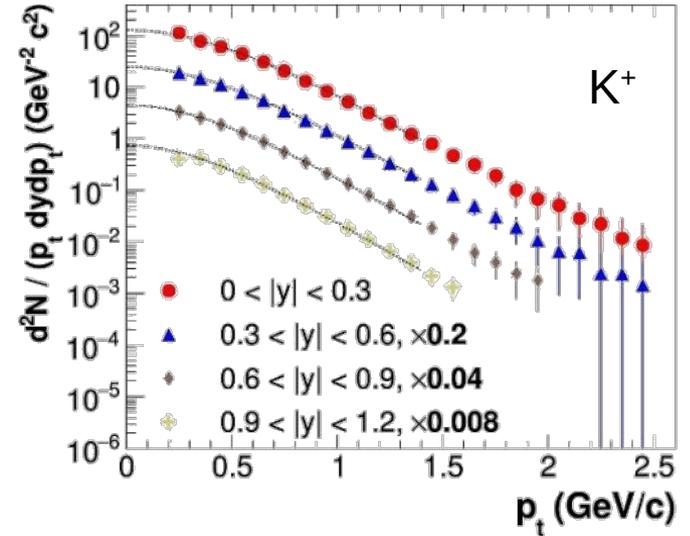
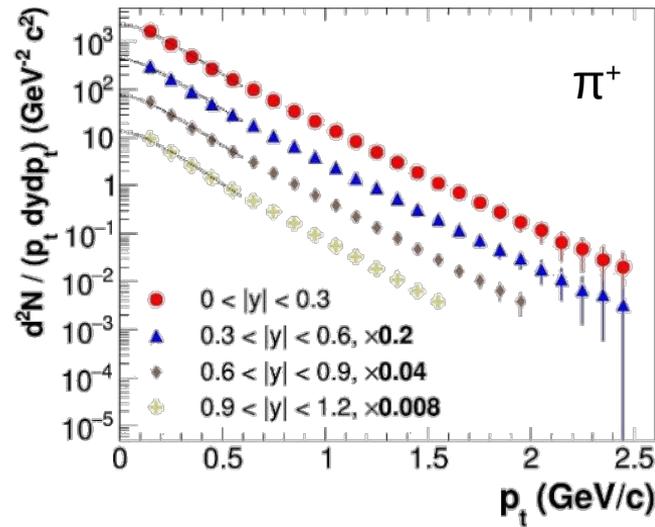
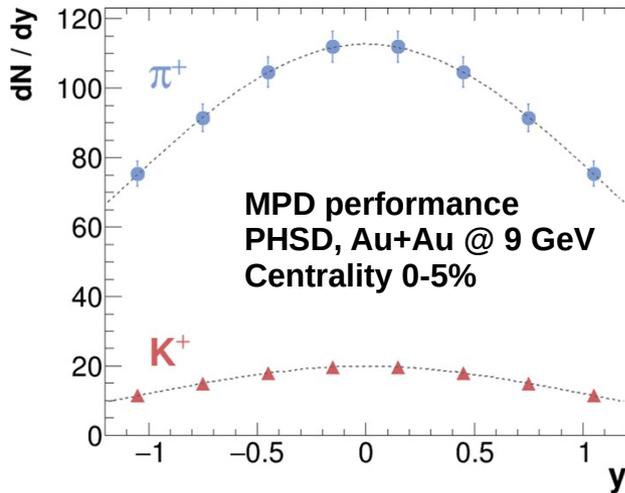
Electromagnetic probes

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

Heavy flavor

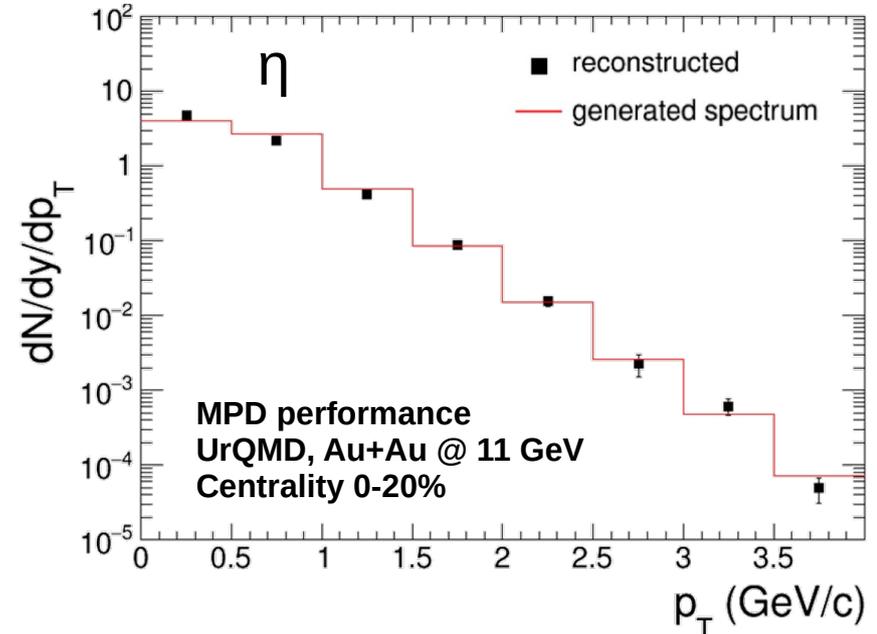
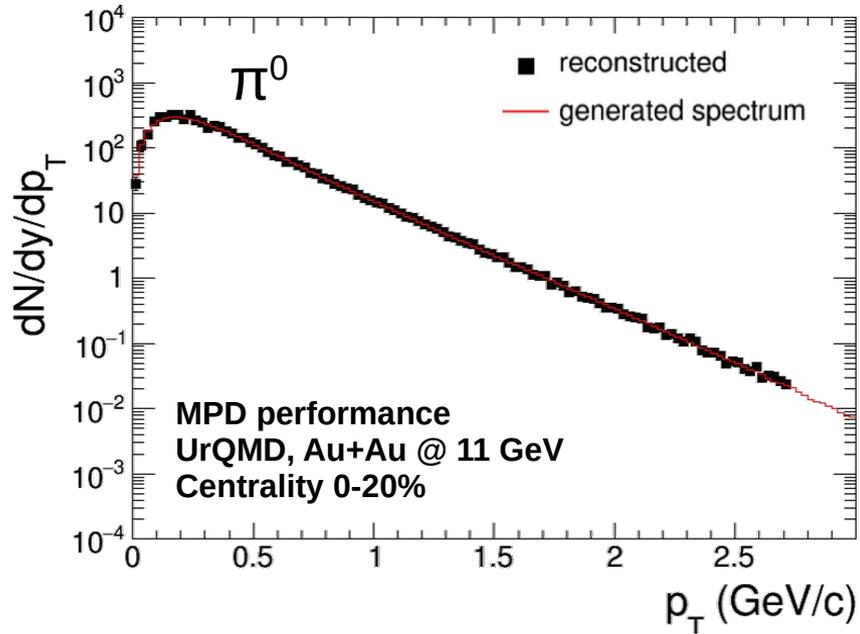
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

MPD performance: charged hadron production



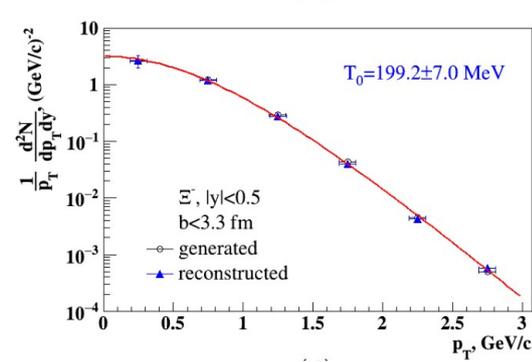
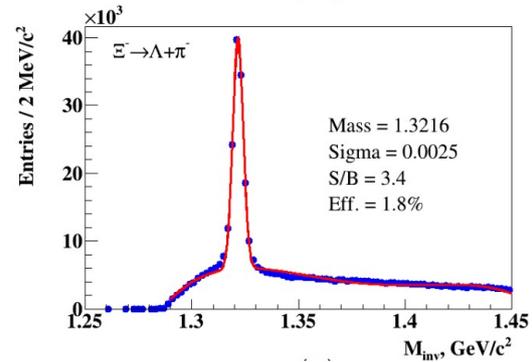
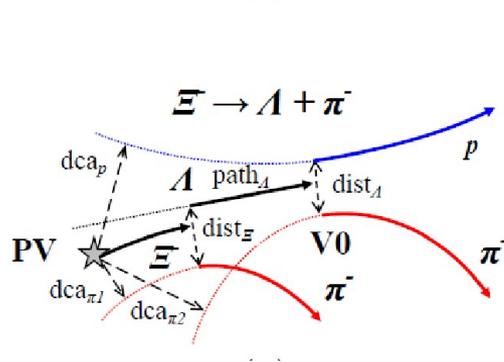
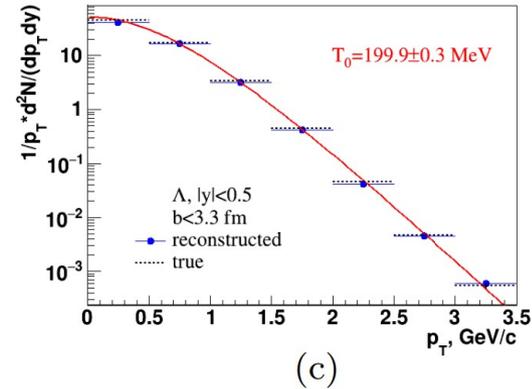
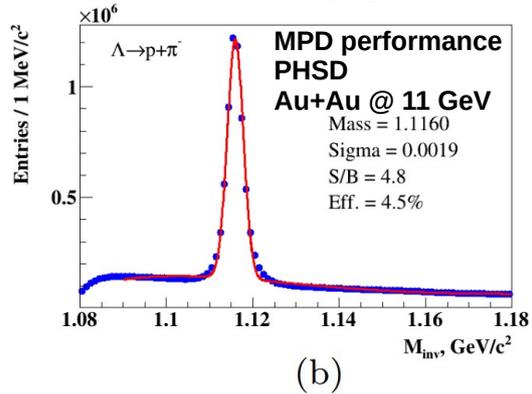
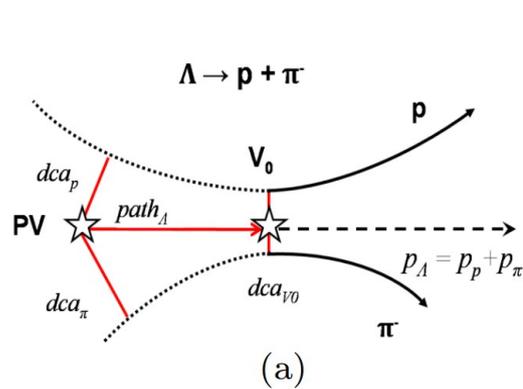
- Probe freeze-out conditions, collective expansion, hadronization mechanisms, strangeness production (“horn” for K/p), parton energy loss, etc. with particles of different masses, quark contents/counts.
- Charged hadrons: large ($\sim 70\%$ the $\pi/K/p$ production) and uniform acceptance + excellent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

MPD performance: neutral hadron production



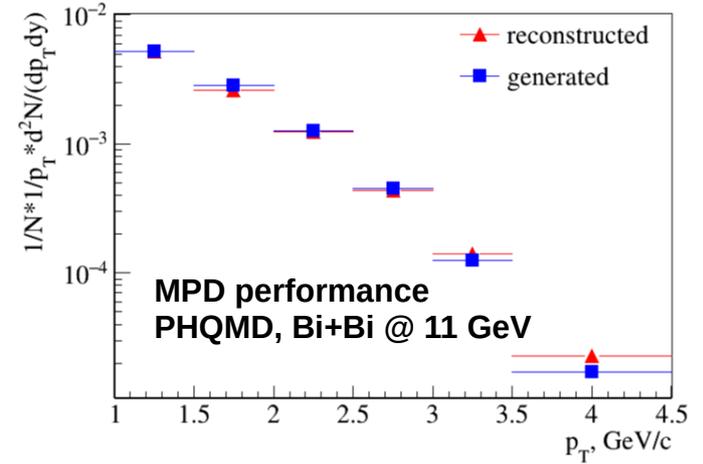
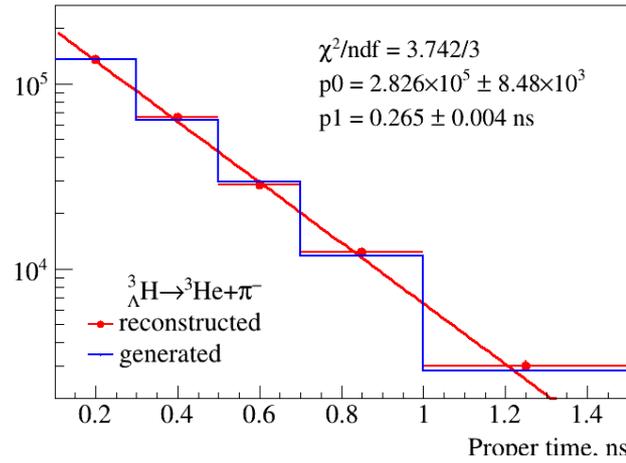
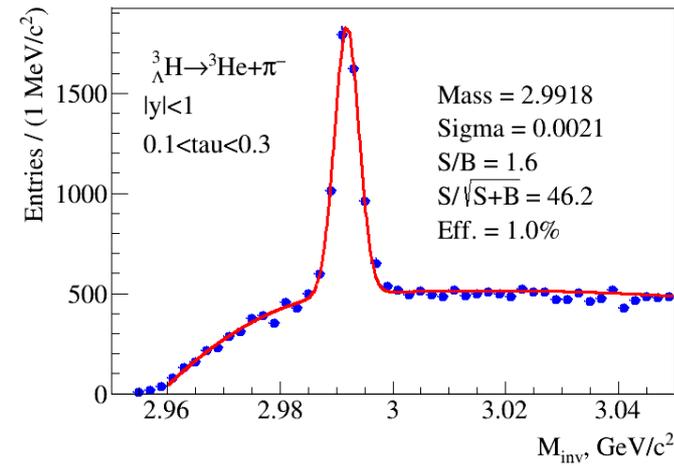
- MPD will be able to measure differential production spectra, integrated yields and $\langle p_T \rangle$, particle ratios, multiplicity distributions for a variety of identified hadrons (π , K, η , ω , p , η')
- Neutral mesons (π^0 , η , K_s , ω , η'): ECAL reconstruction + photon conversion method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

MPD performance: hyperon production



- 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

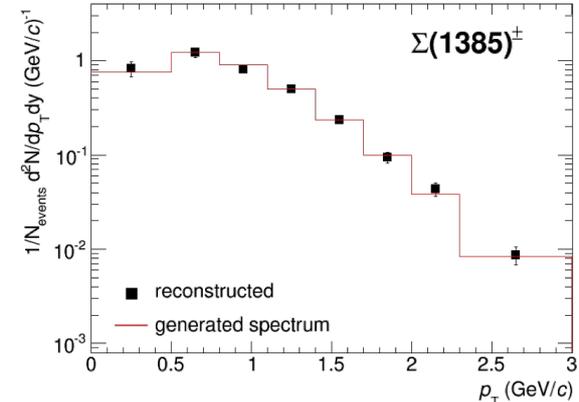
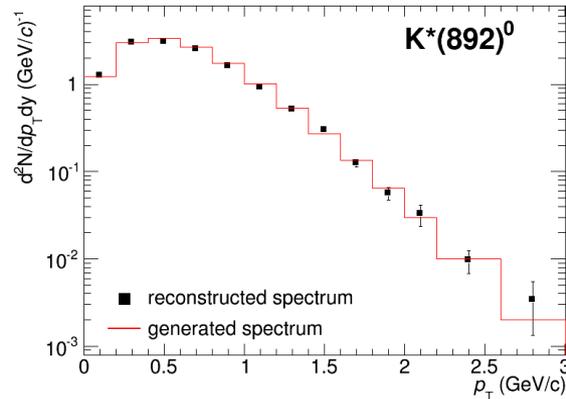
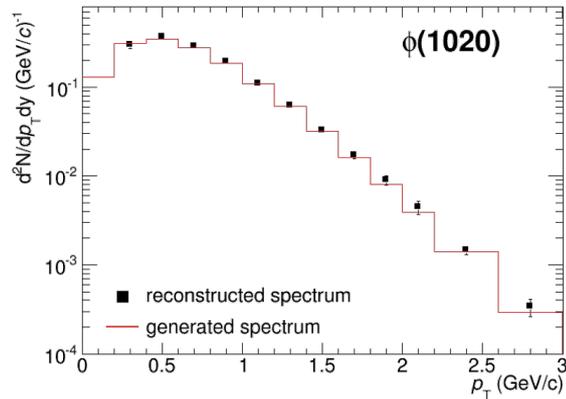
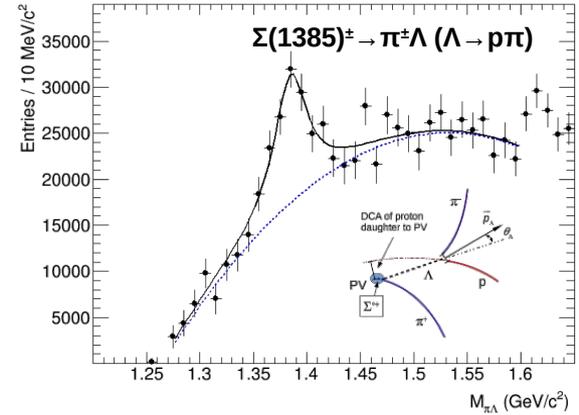
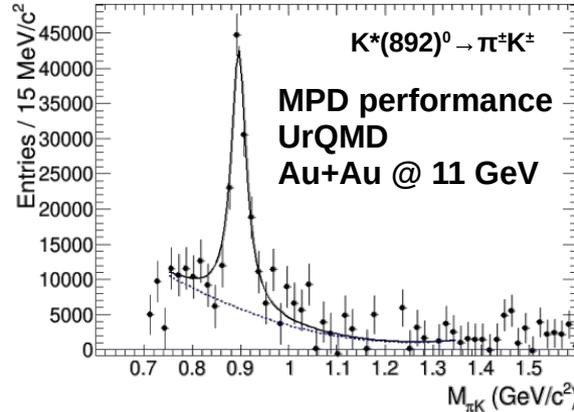
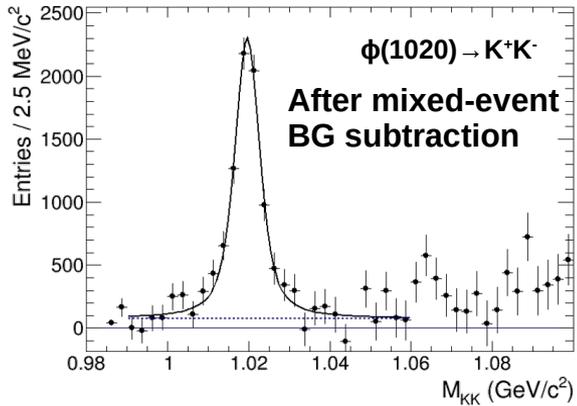
MPD performance: hypernuclei production



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

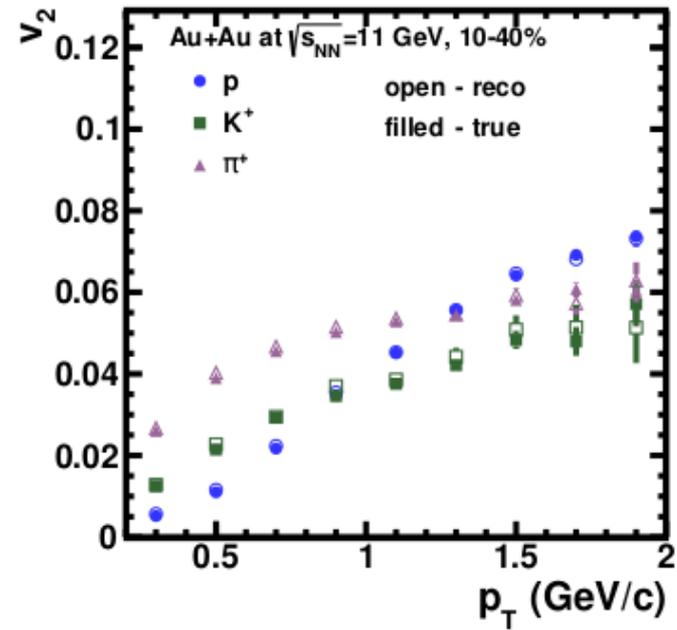
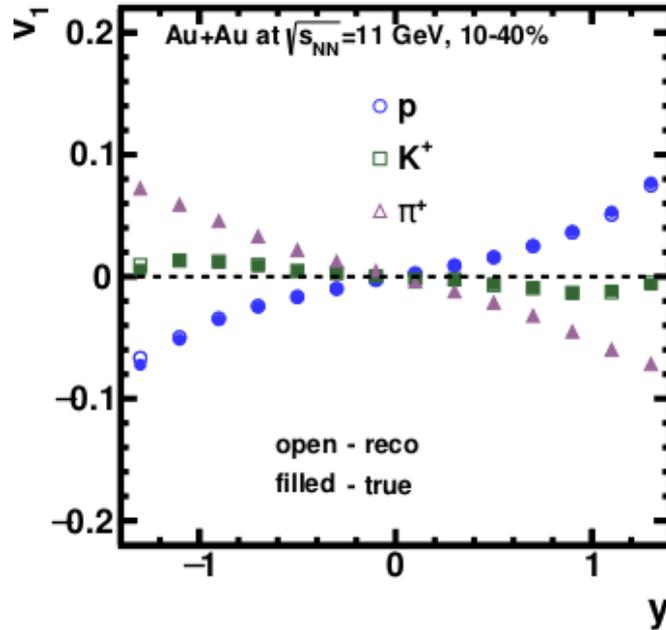
- Hypernuclei measurements may shed light on their production mechanism (statistical hadronization (SHM) or coalescence).
- Statistical models predict enhanced hypernuclear production at NICA energies → even double hypernuclei are reachable.
- Generator yields and lifetimes of hypernuclei are well reproduced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

MPD performance: resonance production



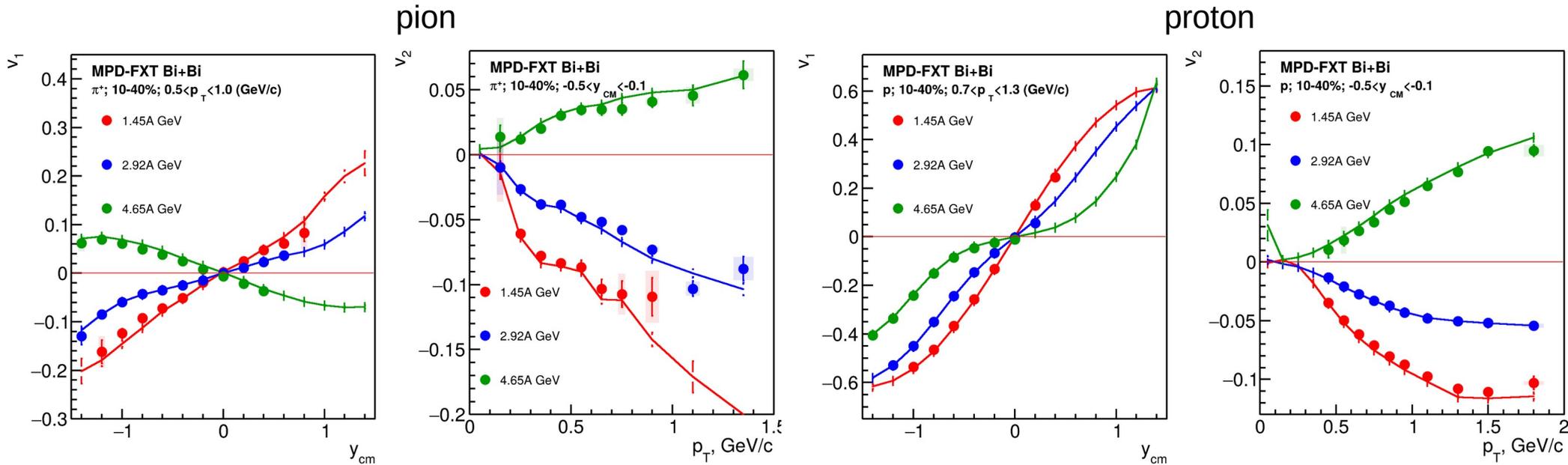
MPD is capable of resonance reconstruction using TPC and TOF identification + selection based on weak decay topology. First measurements are feasible with 10M events.

MPD performance: anisotropic flow



- Anisotropic flow helps constrain transport and compressibility 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, π^\pm , K^\pm . Several methods tested to provide systematics.

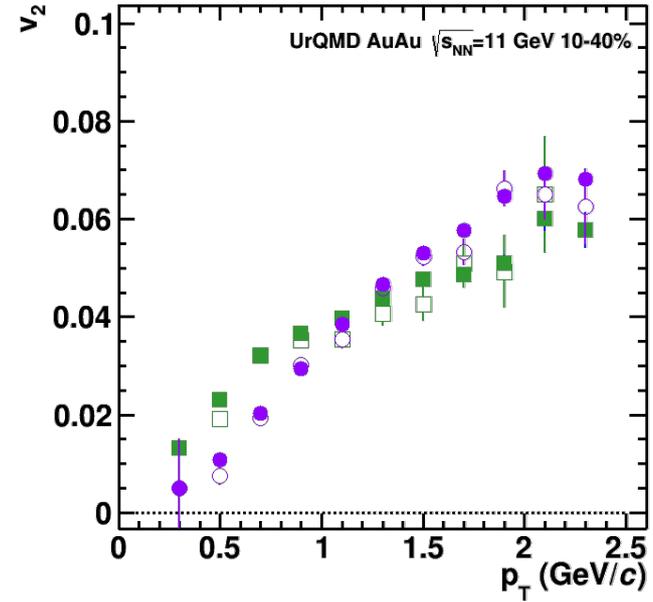
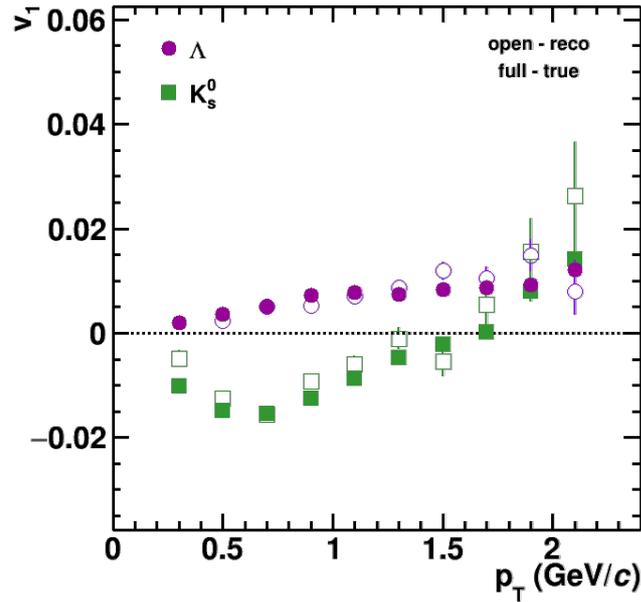
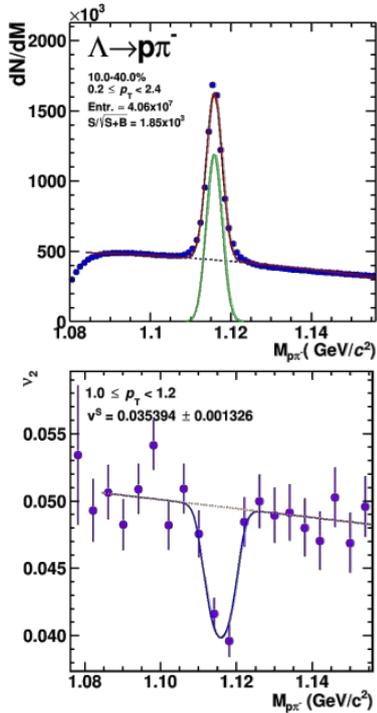
MPD performance: anisotropic flow in FXT mode



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

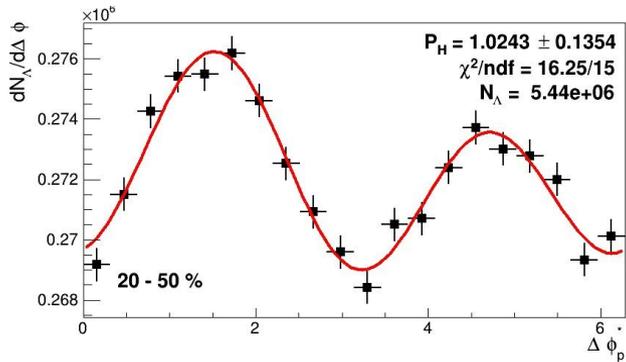
[See talk by P. Parfenov](#)

MPD performance: anisotropic flow of V0

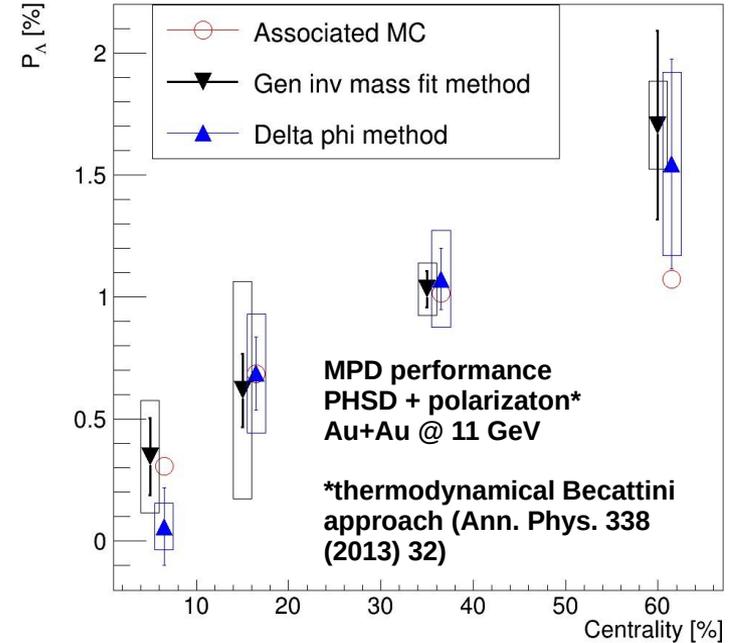
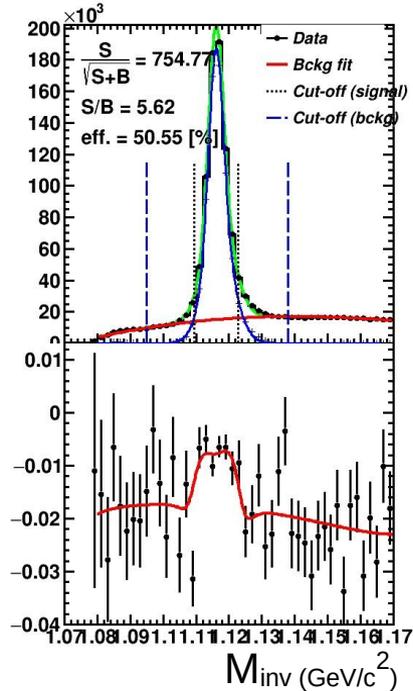


- Differential flow signal extraction using invariant mass fit method
- Reasonable agreement between reconstructed and generated v_n signals for Λ and K_S^0 .
- Similar measurements are possible for other weakly decaying hyperons and short-lived resonances.

MPD performance: global polarization



$$\overline{P}_{\Lambda/\bar{\Lambda}} = \frac{8}{\pi\alpha} \frac{1}{R_{EP}^1} \langle \sin(\Psi_{EP}^1 - \phi^*) \rangle$$

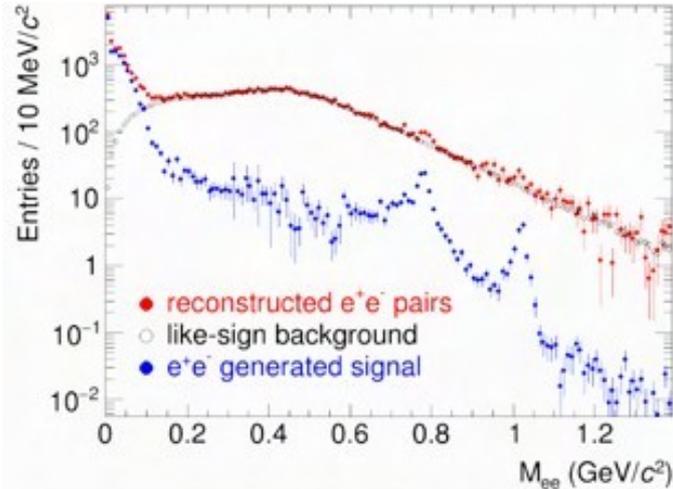


- Large angular momentum and strong magnetic field are formed in mid-central collisions → Vorticity to the QGP and polarization of particles in the final state.
- Invariant mass fit and $\Delta\phi$ methods tested. Measurement for $\Lambda/\bar{\Lambda}$ should be feasible with 15M events.

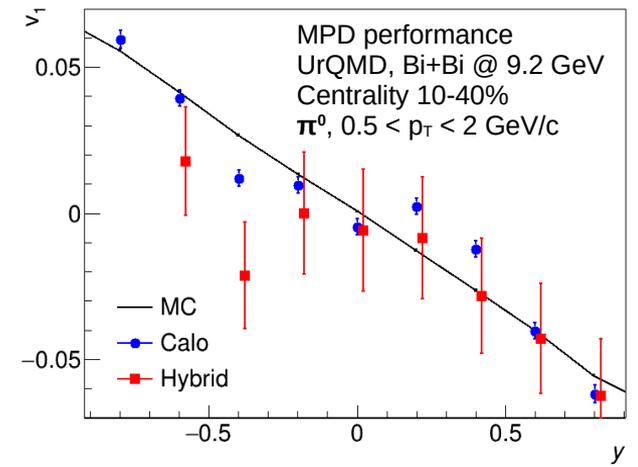
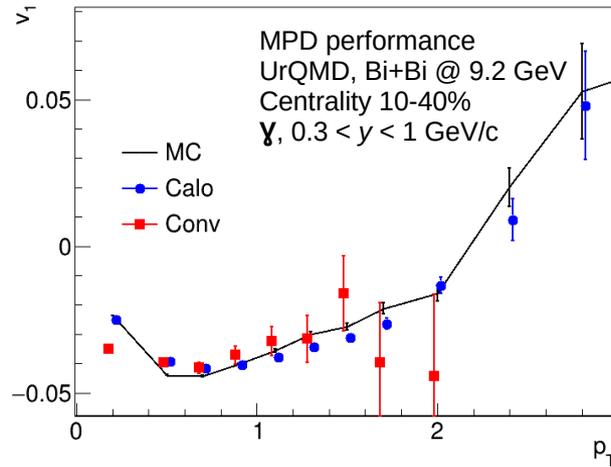
See poster by V. Troshin

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

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