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

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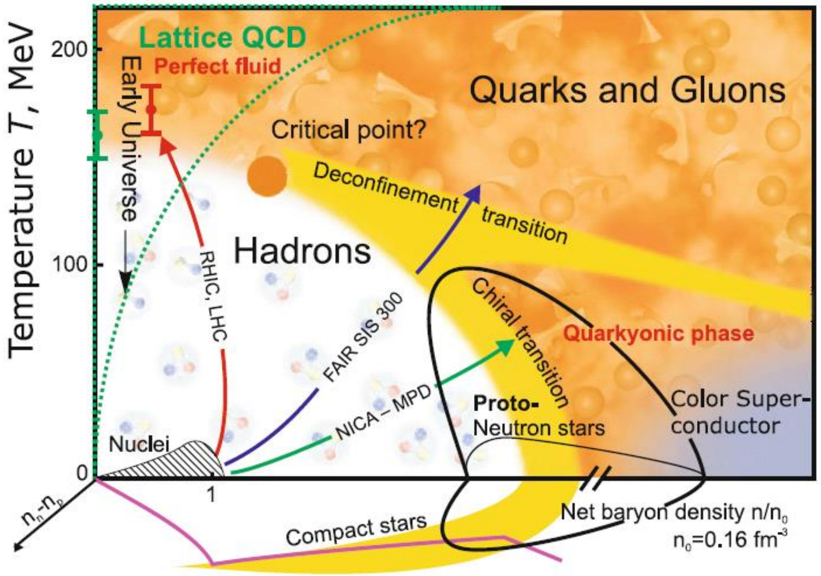
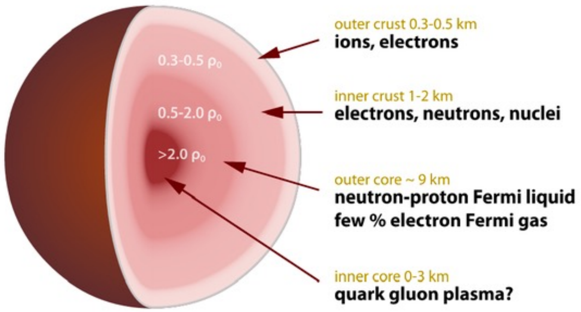
Relativistic heavy-ion collisions

- At μ_B ~ 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





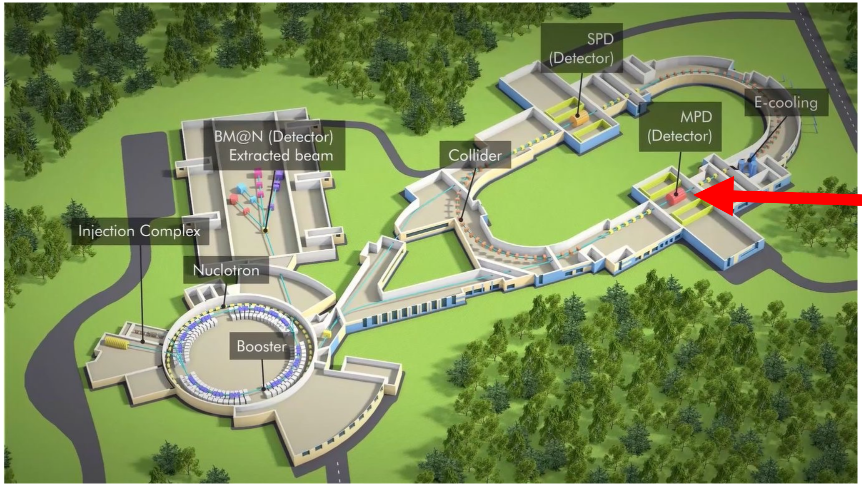
High baryon densities →
→ inner structure of compact stars

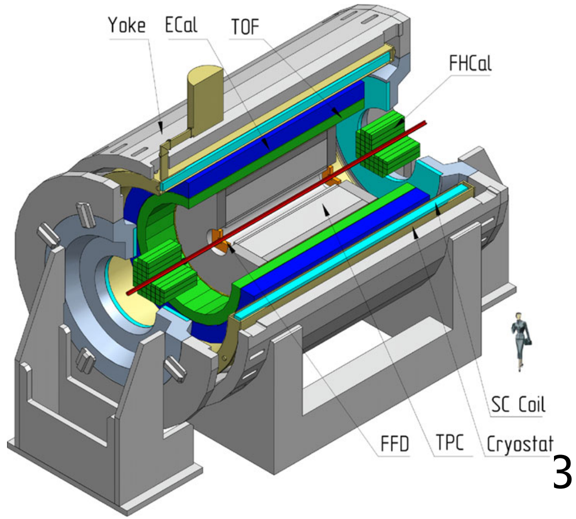
MPD at NICA

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

<u>Main subsystems</u>:

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

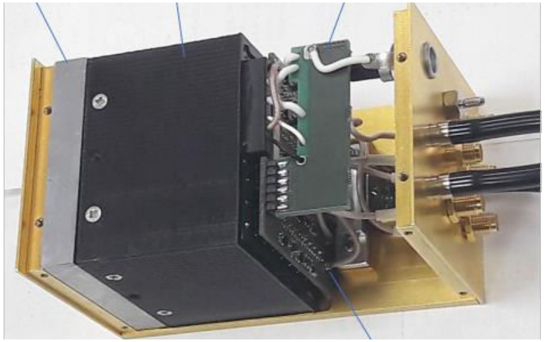
80% of modules

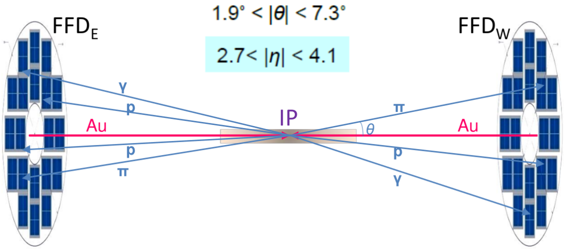
ready in Nov 2024

FHCal

Ready for installation

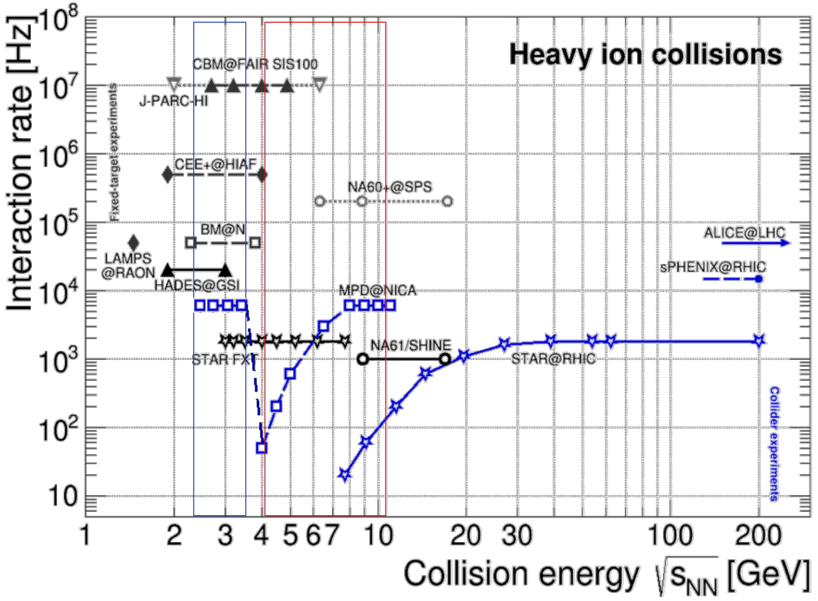
FFD





Ready for installation

Beams and operation modes



First beams (end of 2025):

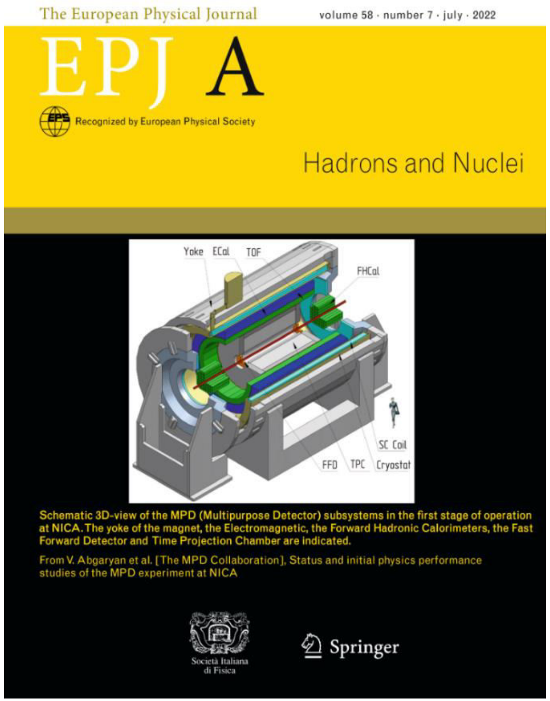
- Bi+Bi/ Xe+Xe at $\sqrt{s_{NN}} \leq 7$ GeV
- Not optimal beam optics resulting in wide z-vertex distribution ($\sigma_z \sim 50$ cm)

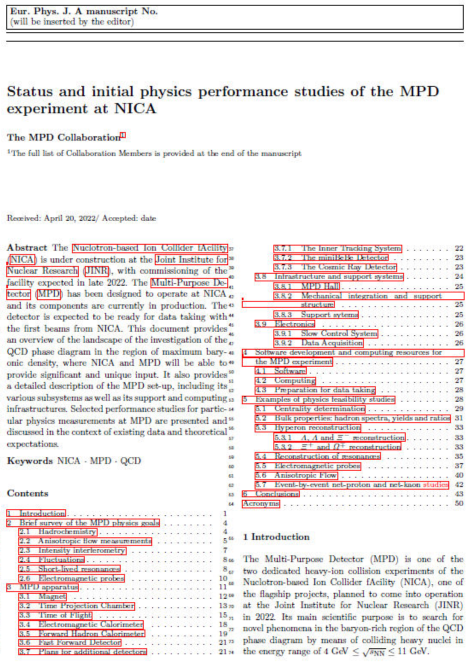
Operation modes:

- Collider
- Fixed-target (one beam and ~100 µm wire close to the edge of the central barrel)
  - extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 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.





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(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

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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.

MPD physics capabilities

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

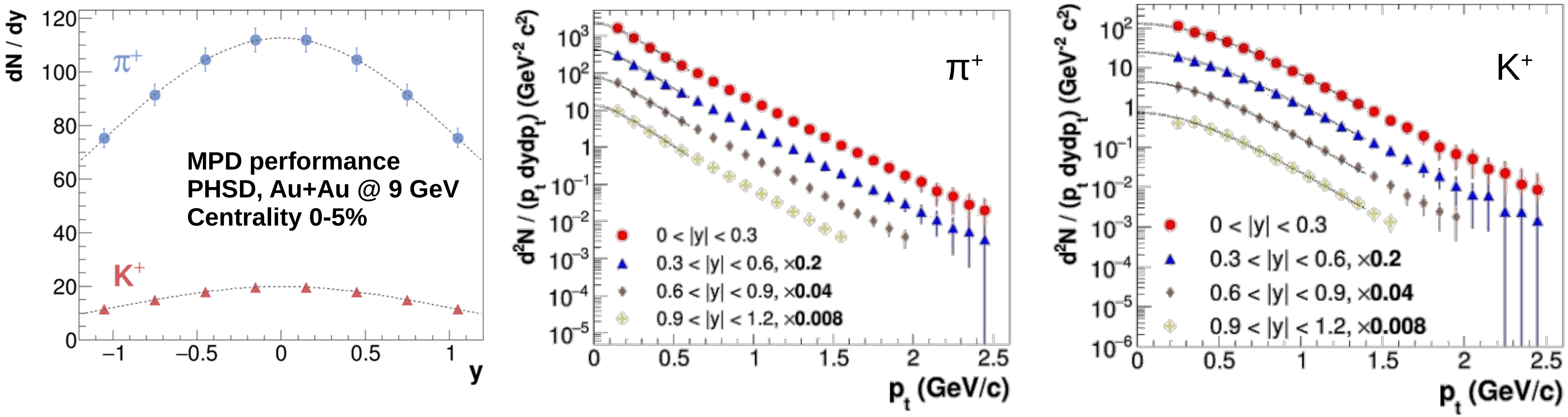
Spectra of light flavor and hypernuclei
- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diagram

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



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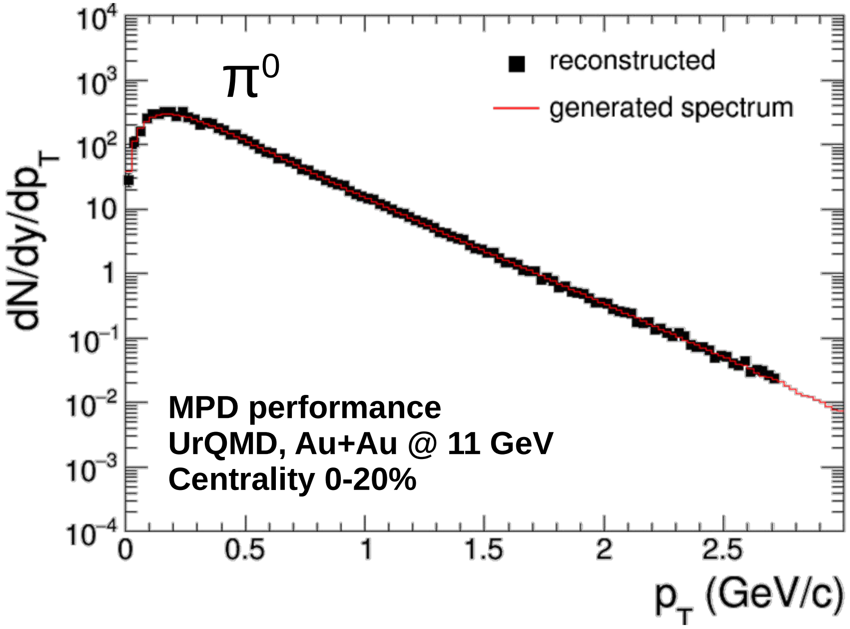
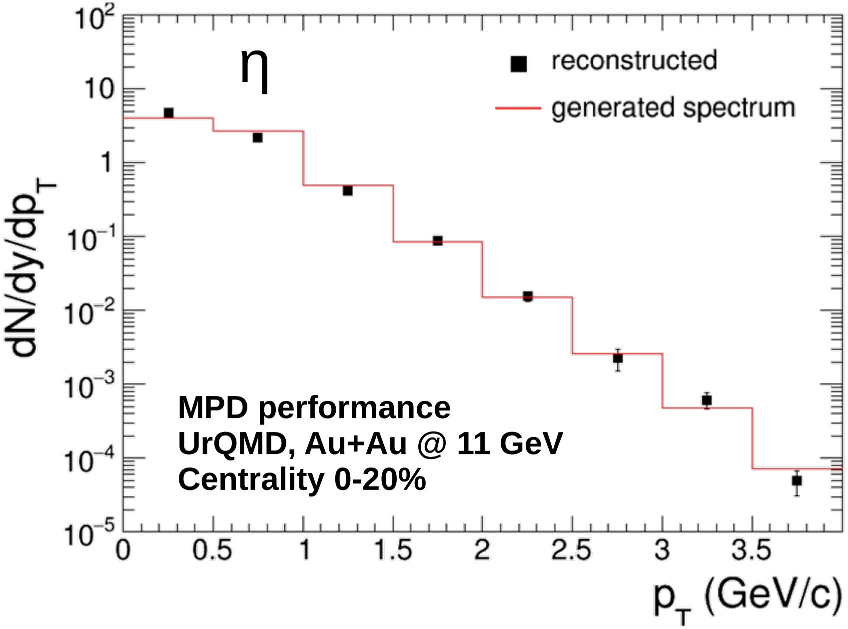
- Probe freeze-out conditions, collective expansion, hadronization mechanisms, strangeness production (“horn” for K/p), parton energy loss, etc. with particles of different masses, quark contents/counts.
- Charged hadrons: large (~ 70% the π/K/p production) and uniform acceptance + excellent PID capabilities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

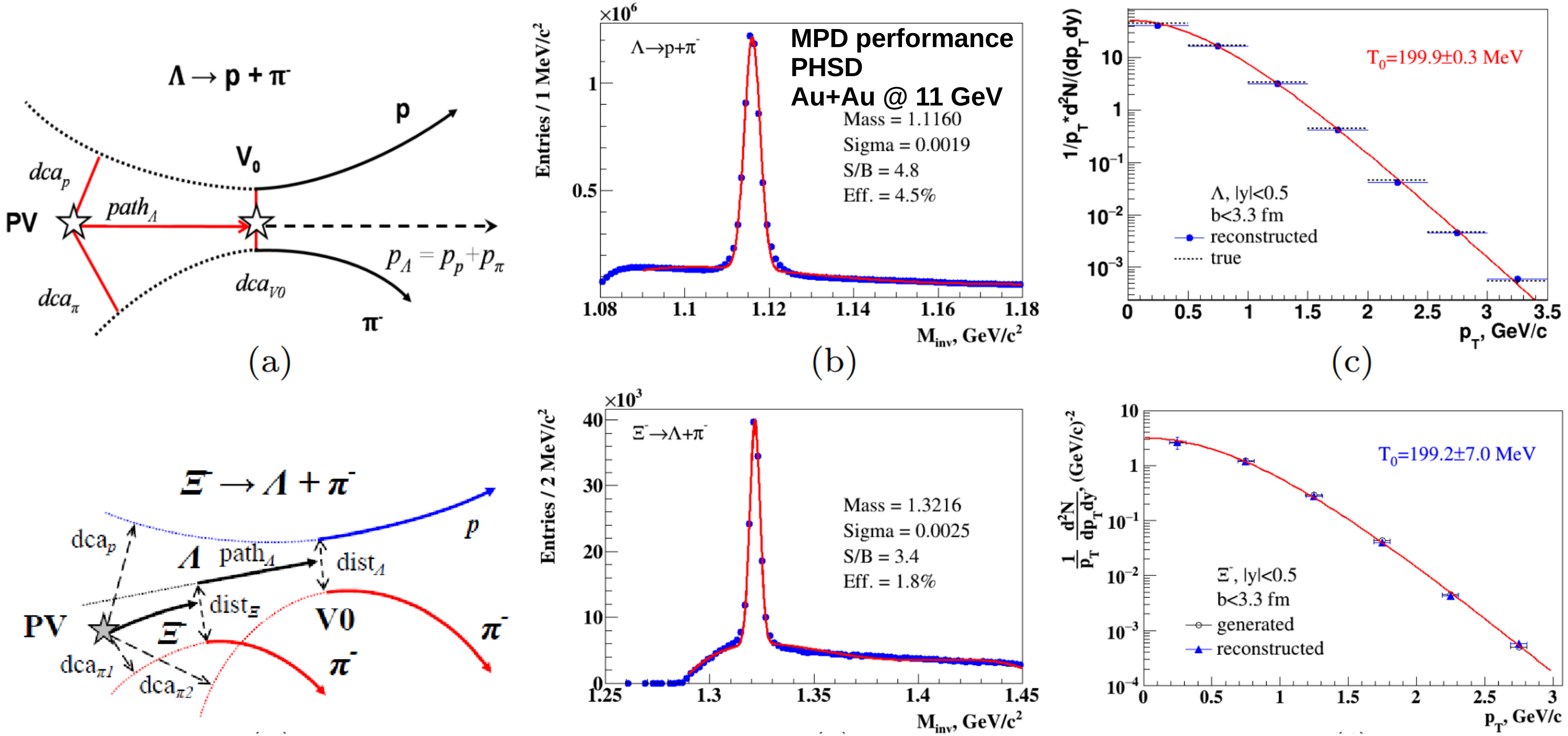
MPD performance: neutral hadron production





- MPD will be able to measure differential production spectra, integrated yields and $<p_T>$, 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



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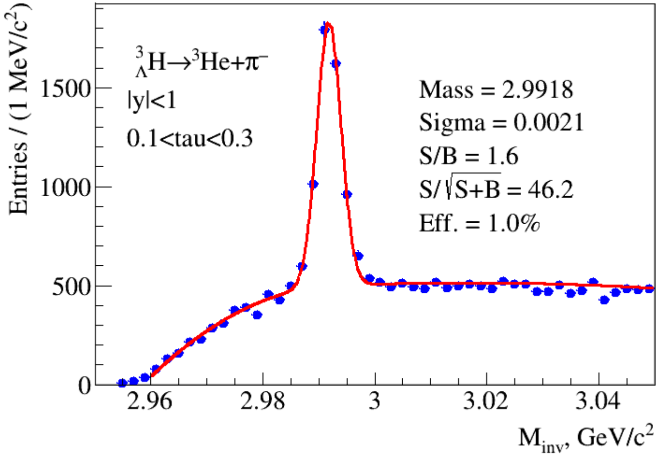
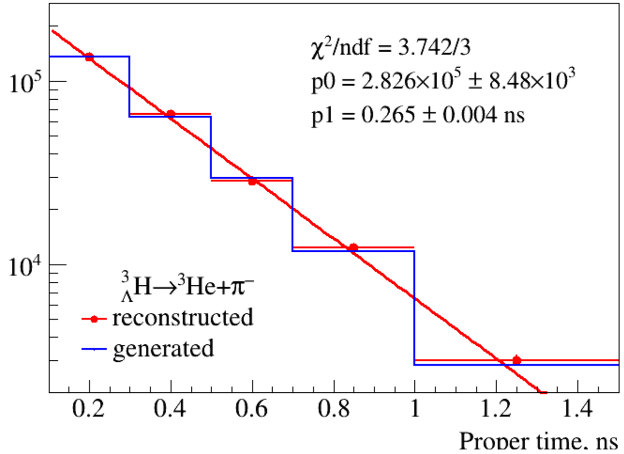
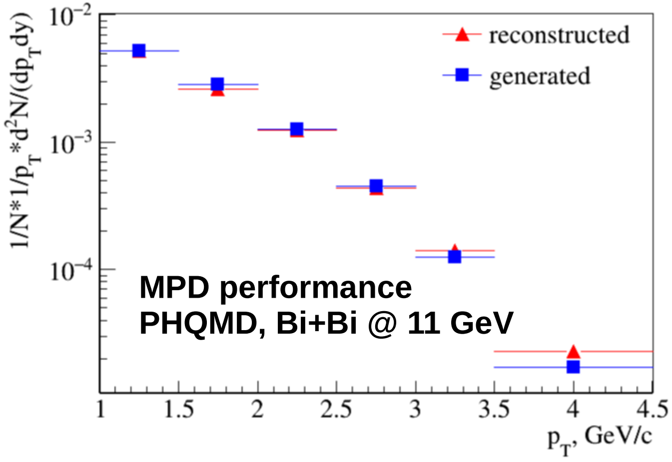
- Strangeness enhancement is considered as a signature of the QGP formation with no consensus on the dominant strangeness enhancement mechanisms – precise measurements needed in pp, pA and AA
- Strange baryons can be reconstructed with good S/B ratios using charged hadron identification in the TPC and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

MPD performance: hypernuclei production







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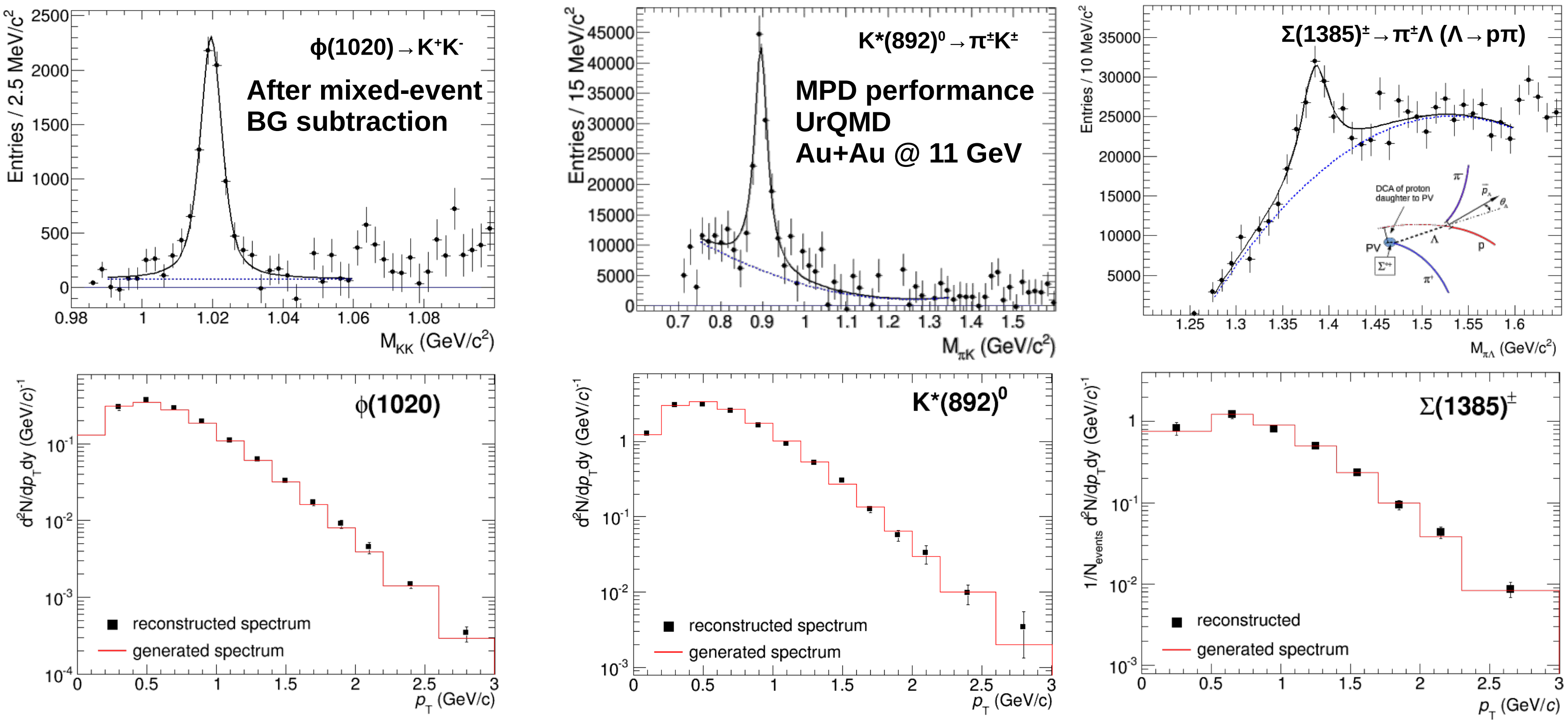
$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right)$$

- 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



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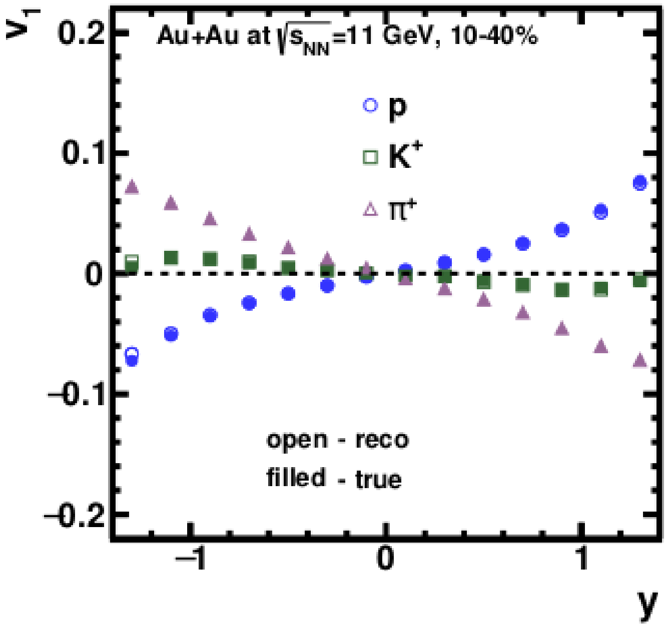
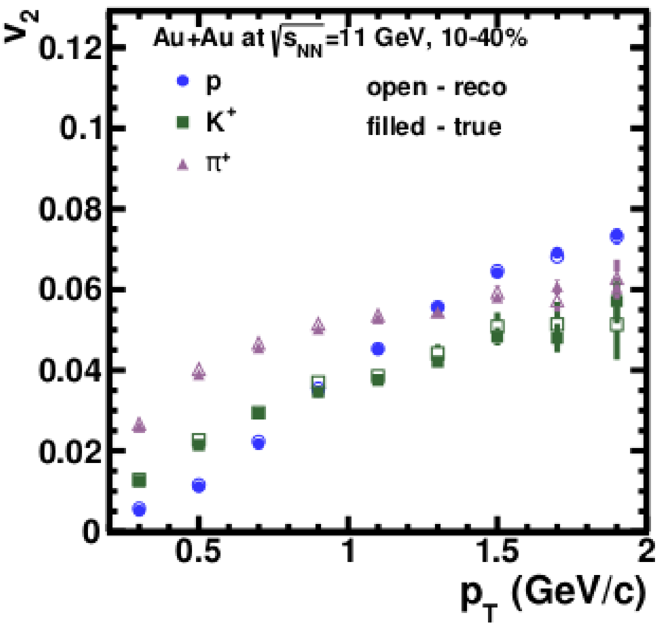
MPD is capable of resonance reconstruction using TPC and TOF identification + selection based on weak decay topology. First measurements are feasible with 10M events.

MPD performance: anisotropic flow





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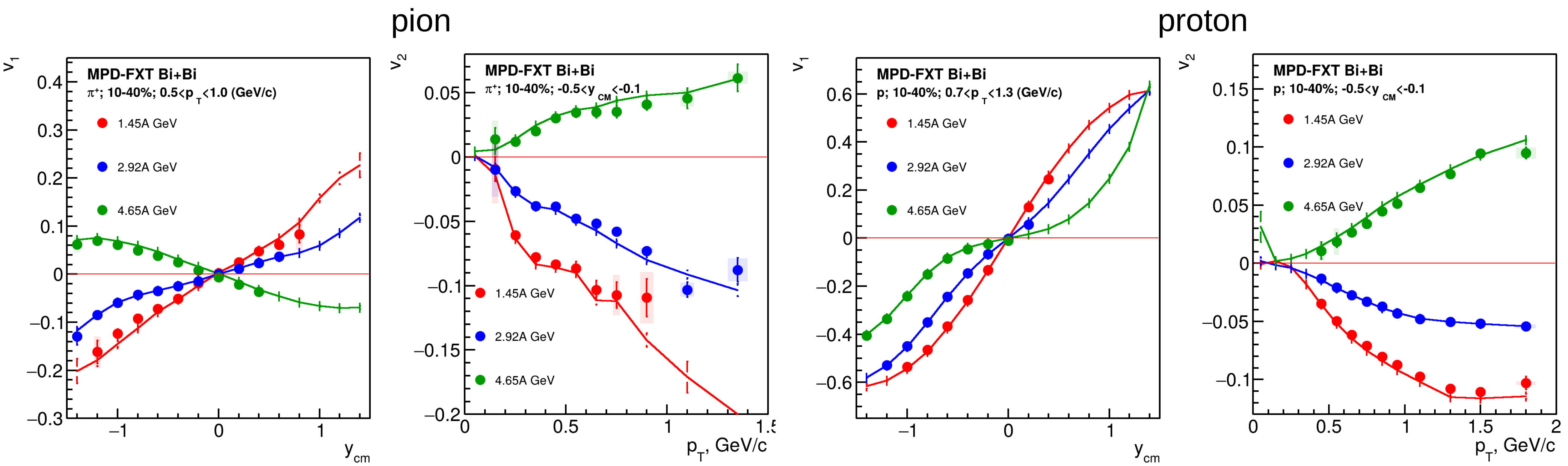
- Anisotropic flow helps constrain transport and compresibility parameters of the matter produced in heavy ion collisions
- Precise reconstruction of directed (v_1) and elliptic (v_2) flow should be possible with MPD for p, $\pi^{\pm}$, $K^{\pm}$. Several methods tested to provide systematics.

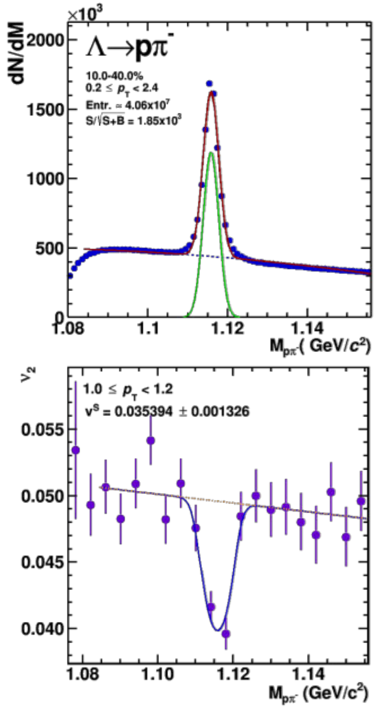
MPD performance: anisotropic flow in FXT mode

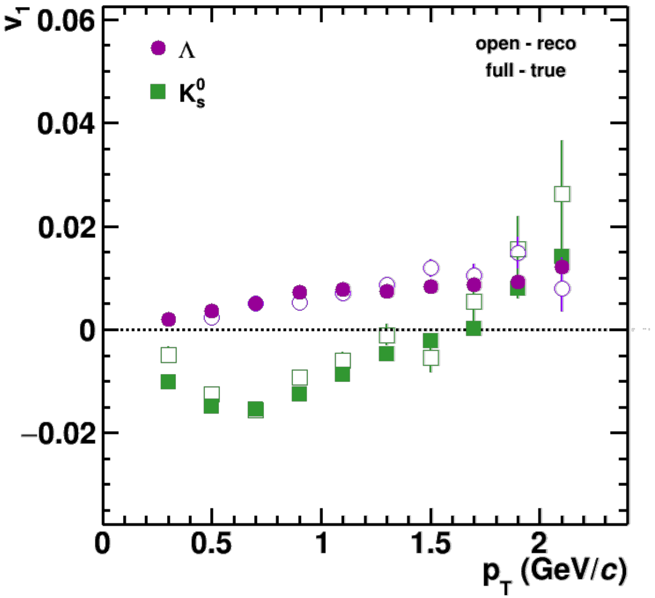


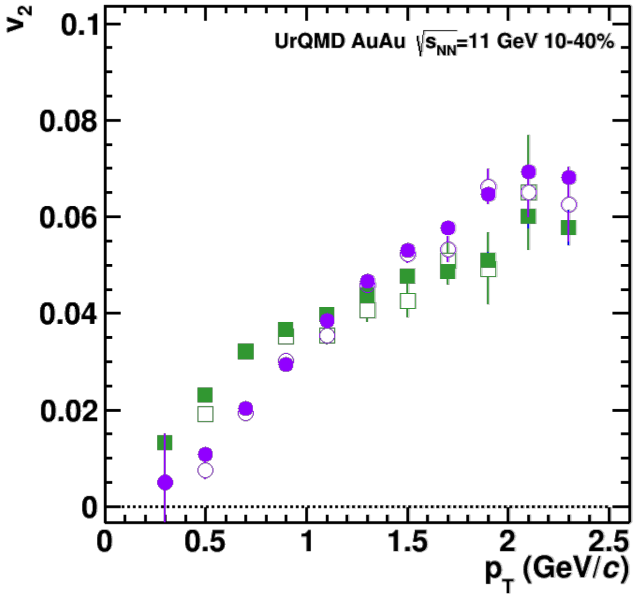
- Good performance of MPD in FXT mode for reconstruction of directed and elliptic flow of protons and charged pions with acceptable coverage of midrapidity.

See talk by P. Parfenov

MPD performance: anisotropic flow of V0







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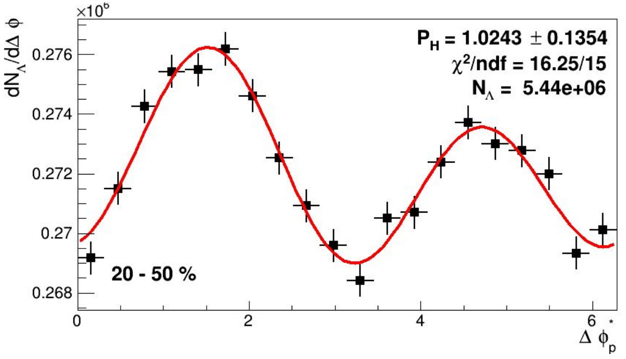
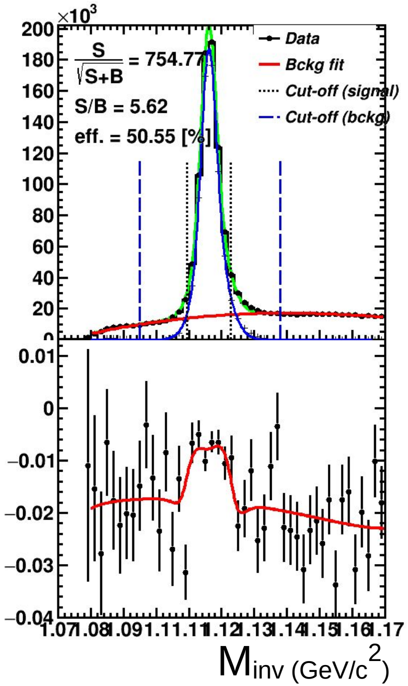
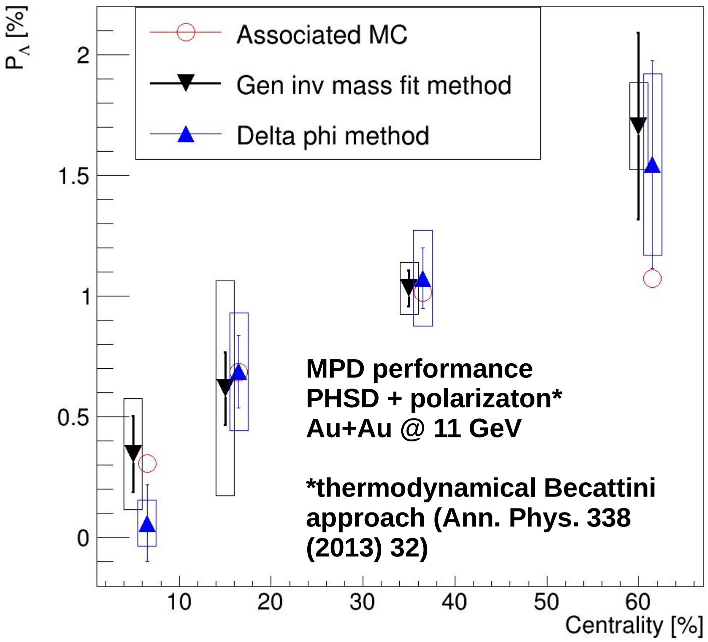
- Differential flow signal extraction using invariant mass fit method
- Reasonable agreement between reconstructed and generated v_n signals for Λ and K^0_S.
- Similar measurements are posible for other weakly decaying hyperons and short-lived resonances.

MPD performance: global polarization



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





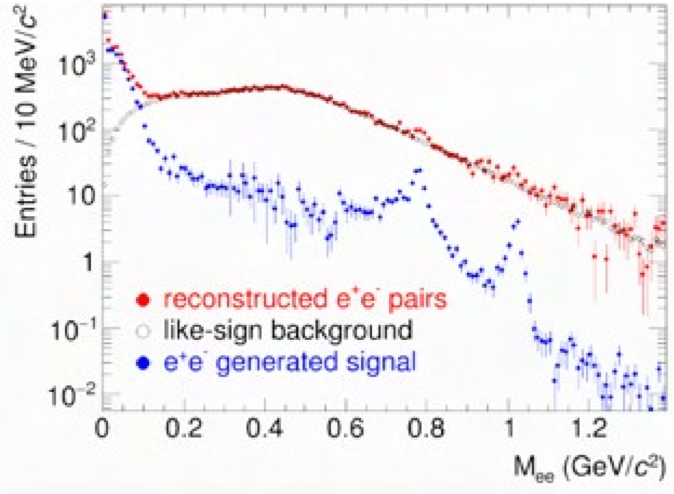
- Large angular momentum and strong magnetic field are formed in mid-central collisions → Vorticity to the QGP and polarization of particles in the final state.
- Invariant mass fit and Δφ methods tested. Measurement for $\Lambda/\bar{\Lambda}$ should be feasible with 15M events.

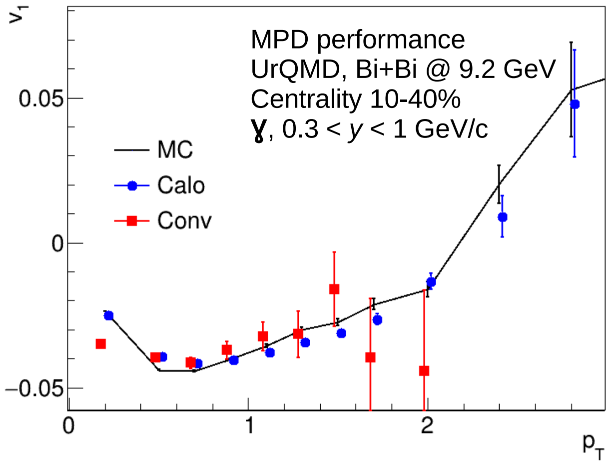
<u>See poster by V. Troshin</u>

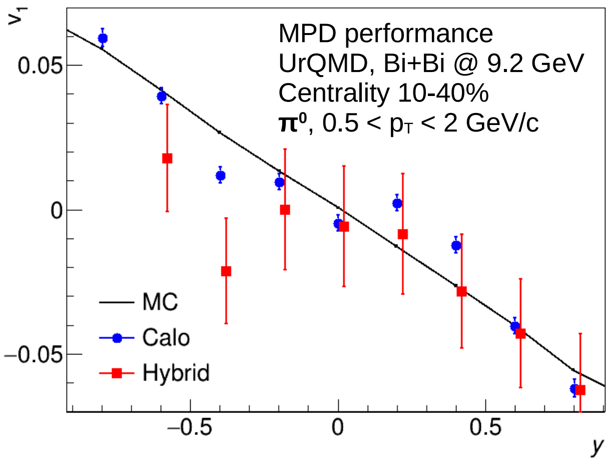
MPD performance: in progress

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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