Flow performance studies with MPD (NICA)

MEPhI:  A. Anikeev, A. Demanov, O. Golosov, E. Kashirin, P. Parfenov, I. Segal, I. Selyuzhenkov (MEPhI, GSI), A. Taranenko, A. Truttse
JINR: P. Batyuk, N. Geraksiev (Plovdiv Uni), V. Kireyeu, A. Mudrokh
NC KI: D. Blau

5th MPD Collaboration Meeting,
JINR, Dubna, April 23-24, 2020

Project supported by RFBR № 18-02-40086
Anisotropic Flow at RHIC-LHC

\[ \epsilon_n = \sqrt{\left\langle r^n \cos n\phi \right\rangle + \left\langle r^n \sin n\phi \right\rangle} \]

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

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

Different methods, non-flow, fluctuations.
Anisotropic flow at NICA energies is a delicate balance between:
(i) the ability of pressure developed early in the reaction zone and
(ii) the passage time for removal of the shadowing by spectators
Anisotropic flow at NICA energies: Data vs Models

Anisotropic flow at NICA energies  Experimental Data:
(1) E895 Collaboration Au+Au at 2.7, 3.32, 3.85 and 4.3 GeV
(2) NA61/NA49 Pb+Pb at 5.1, 7.6 and 8.9 GeV
(3) STAR Collaboration Au+Au at 4.5, 7.7 and 11.5 GeV

Anisotropic flow at NICA energies  Models:
(1) String/Hadronic Cascade Models: UrQMD, HSD, SMASH, JAM, DCM-QGSM
(2) Hybrid Models: viscous hydro+cascade (vHLLE+UrQMD и MUSIC+UrQMD) и parton/string models (AMPT, PHSD и PHQMD)

Directed flow: Models vs Data comparison

Models: DCM-QGSM-SMM and UrQMD vs STAR published data for Au+Au at $\sqrt{s_{NN}} = 7.7$ GeV (Phys. Rev. Lett. 112, no. 16, 162301 (2014))
Directed flow: Models vs Data comparison

Models JAM (1PT vs XPT EOS) vs STAR published data for Au+Au at $\sqrt{s_{NN}} = 7.7$ GeV (Phys. Rev. Lett. 112, no. 16, 162301 (2014))
Pure String/Hadronic Cascade models give smaller $v_2$ signal compared to STAR data for Au+Au $\sqrt{s_{NN}}=7.7$ GeV.
Differential elliptic flow: 3D hydro vHLLE + UrQMD

\[ \text{Au+Au} \ \sqrt{s_{NN}}=7.7 \text{ GeV, charged hadrons h}^\dagger, \ 20-30 \% \]

\[ \text{Phys. Rev. C 86 (2012) 54908} \]

3D hydro model vHLLE + UrQMD shows sensitivity of \( v_2 \) to the EoS (XPT EoS vs 1PT EoS) and specific shear viscosity (\( \eta/s \))

24.04.2020
Flow performance study at MPD (NICA)

Multi Purpose Detector (MPD)

Time projection chamber (TPC)

EP plane
FHCal (2<|η|<5) or TPC (|η|<1.5)

Time Projection Chamber (TPC)
• Tracking of charged particles
• within (|η| < 1.5, 2π in φ )
• PID at low momenta

Time of Flight (TOF)
• PID at high momenta

Forward Hadron Calorimeter (FHCal)

-5<η<-2

-1.5<η<1.5
TPC
0.2<p_T<3 GeV/c

2<η<5
FHCal
Setup, event and track selection

UrQMD → GEANT4 → Reconstruction → Flow analysis

- **Au+Au,** $N_{\text{events}} = 8\ \text{M events}$
  - at $\sqrt{s_{NN}} = 4.5, 7.7$ and $11\ \text{GeV}$
- **Bi+Bi,** $N_{\text{events}} = 8\ \text{M events}$
  - at $\sqrt{s_{NN}} = 7.7\ \text{GeV}$

Event classification:
- Track multiplicity
- FHCal energy

Track selection:
- Primary tracks (2σ DCA cut)
- $N_{\text{TPC hits}} > 32$
- $p_T > 0.2\ \text{GeV/c}$
- $|\eta| < 1.5$
- PID based on TPC+TOF (MpdPid)

**MPDRoot, December 2019**
This centrality procedure was used in CBM, NA49, and NA61/SHINE: Acta Phys.Polon.Supp. 10 (2017) 919
Implementantion in MPD: https://github.com/IlyaSegal/NICA

Parfenov, P., Selyuzhenkov I., Segal, I.

24.04.2020
MC Glauber Centrality Framework

$\langle b \rangle_{\text{MC}}$ vs Centrality, %

$\langle b \rangle_{\text{UrQMD}}$ vs Centrality, %

$\langle N_{\text{part}} \rangle$ vs $b$, fm

$\langle N_{\text{part}} \rangle$ vs Centrality, %
Expected small difference between MC Glauber eccentricities for Au+Au and Bi+Bi
Both left and right FHCal parts were used:

\[ Q_x^m = \frac{\sum E_i \cos(m\varphi_i)}{\sum E_i}, \quad Q_y^m = \frac{\sum E_i \sin(m\varphi_i)}{\sum E_i} \]

\[ \Psi_m^{EP} = \frac{1}{m} \text{ATan2}(Q_y^m, Q_x^m) \]

\[ m = 1 \text{ was used} \]

- \( E_i \) is the energy deposition in \( i \)-th FHCal module
- \( \varphi_i \) is its azimuthal angle.
- For \( m=1 \) weights had different signs for backward and forward rapidity.
- \( \Delta\eta\text{-gap}>0.5 \) between TPC and FHCal suppresses non-flow contribution

\[ Res^2\{(\psi_n^{EP,L}, \psi_n^{EP,R})\} = \langle \cos[n(\psi_n^{EP,L} - \psi_n^{EP,R})] \rangle \]

\[ Res_m\{\psi_n^{EP,\text{true}}\} = \langle \cos[n(\psi_{RP} - \psi_n^{EP})] \rangle \]

\[ \nu_n = \frac{\langle \cos[n(\psi_{RP} - \psi_n^{EP})] \rangle}{Res_m\{\psi_n^{EP,\text{true}}\}} \]

Energy distribution in FHCal

https://git.jinr.ru/nica/mpdroot/tree/dev/macro/physical_analysis/Flow
Good performance in the centrality range 0-80% for NICA collision energy range
Expected small difference between EP resolutions for Au+Au and Bi+Bi
$p_T$-dependence of $v_1$ and $v_2$ of reconstructed signal

Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation.
$v_2(p_T)$: FHCal EP vs TPC EP

Expected small difference between $v2$ measured with respect TPC (EP2 plane) and FHCal (EP1 plane)
$v_n(p_T)$: Bi+Bi vs Au+Au

Expected small difference for $v1$ and $v2$ for particles produced in Au+Au and Bi+Bi collisions.
$v_1(y)$: Bi+Bi vs Au+Au

Expected small difference for $v_1(y)$ for particles produced in Au+Au and Bi+Bi collisions.

24.04.2020
Anisotropic Flow of V0 Particles (Nikolay Geraksiev)

- Currently:
  25 million events, UrQMD 3.4 non-hydro, 11.0 GeV, minbias
- Geant4 simulation, full reconstruction with:
  - TPCv7, TOFv7, FHCal
- Centrality by TPC multiplicity, Event-plane method with FHCal
- Particle decays reconstructed with MpdParticle realistic cuts
  Differential flow signal extraction by bins in transverse momentum (or rapidity) with a simultaneous fit

\[ v_2^{SB}(m_{inv},p_T) = v_2^S(p_T) \frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_2^B(m_{inv},p_T) \frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} \]

- Outlook:
  Larger statistics with vHLLE (hydrodynamic evolution)
  Larger signal magnitude due to hydro (realistic input)
  Latest versions of detector geometry
  Multi-variate analysis for reconstructed particle selection (TMVA)

24.04.2020
Flow at MPD (NICA)

1. Plovdiv University "Paisii Hilendarski", Bulgaria
2. VBLHEP JINR, Russia
Summary

Anisotropic flow performance study in MPD (NICA):

A full reconstruction chain was implemented:
- Combined particle identification based on TPC and TOF
- Realistic hadronic simulation (GEANT4)
- Event plane from FHCal and TPC

Reconstructed $v_1, v_2$ are in agreement with MC generated data for Au+Au and Bi+Bi

Model/Data comparison:
- Pure string/hadronic cascade models give smaller $v_2$ signal compared to STAR data for Au+Au $\sqrt{s_{NN}}=7.7$ GeV
- $p_T$ from 3D hydro model vHLLE + UrQMD and AMPT model are in good agreement with STAR data

Elliptic flow are sensitive to the EoS (1PT or XPT) and $\eta/s$

The situation with good model description worse for directed flow

Thank you for your attention!
Backup
BES: differential elliptic flow: UrQMD

Au+Au $\sqrt{s_{NN}}=7.7$ GeV, charged hadrons $n^+$, 20-30 %

What about other “hadronic” models: SMASH, JAM, HSD? - Under investigation

23.10.2019
BES: differential elliptic flow: UrQMD

What about other “hadronic” models: SMASH, JAM, HSD? - Under investigation

23.10.2019
Elliptic and triangular flow of charged hadrons at RHIC BES


Hybrid model: UrQMD + 3D hydro model vHLLE + UrQMD
Shows good agreement with published STAR data for integrated $v_n(\sqrt{s_{NN}})$ from BES-I

23.10.2019
Differential elliptic flow: 3D hydro vHLLE + UrQMD

Au+Au $\sqrt{s_{NN}}=7.7$ GeV, charged hadrons $h^+$, 20-30 %

Results were obtained using interface developed by P. Batyuk (JINR): https://github.com/pbatyuk/vHLLE_package

Good agreement with STAR published data

3D hydro model vHLLE + UrQMD (XPT EoS), $\eta/s = 0.2$ + param. from Phys.Rev. C91 (2015) no.6, 064901


Differential elliptic flow: 3D hydro vHLLE + UrQMD

ch. hadrons $h^\pm$, Au+Au $|s_{NN}|=7.7$ GeV, 10-20 %

ch. hadrons $h^\pm$, Au+Au $|s_{NN}|=7.7$ GeV, 20-30 %
Differential elliptic flow of pions: 3D hydro vHLLE + UrQMD

At NICA energies the elliptic flow if different for particles and anti-particles!

3D hydro model vHLLE + UrQMD (XPT EoS), $\eta/s = 0.2 +$ param. from Phys.Rev. C91 (2015) no.6, 064901
Differential elliptic flow of pions: 3D hydro vHLLE + UrQMD

At NICA energies the elliptic flow is different for particles and anti-particles!

A. A. 

23.10.2019
Differential elliptic flow: 3D hydro vHLLE + UrQMD

3D hydro model vHLLE + UrQMD (XPT EoS), $\eta/s = 0.2 + \text{param. from Phys.Rev. C91 (2015) no.6, 064901}$

Results were obtained using interface developed by P. Batyuk (JINR): https://github.com/pbatyuk/vHLLE_package

Reasonable agreement with STAR published data – need tuning?
**Differential elliptic flow: 3D hydro vHLLE + UrQMD**

3D hydro model vHLLE + UrQMD (XPT EoS vs 1PT EoS) shows sensitivity of $v_2$ to the EoS $v_3=0$ for pure UrQMD ??

Model will be used for the flow performance study ($v_2$ and $v_3$) at MPD (NICA)

---


**Phys. Rev. C 91 (2015) no.6, 064901**
Eccentricity: Comparison w/ UrQMD

Notable difference between MC Glauber and UrQMD eccentricities

Common data format for all models: UrQMD, SMASH, PHSD, JAM, AMPT
FHCal and TPC acceptance

- **TPC** - charged particles at midrapidity (participants)
- **FHCal** - hadrons at forward rapidity (spectators)
Track selection

- \( N_{\text{TPC hits}} > 32 \)
- \( |p_T| < 3 \)
- \( |\eta| < 1.5 \)
- PID based on TPC+TOF (MpdPid)
Particle identification based on TPC + TOF

Low momentum:
dE/dx from TPC

High momentum:
m² estimated from TOF signal
Resolution correction factor: GEANT3 vs GEANT4 comparison

GEANT4 has more realistic hadronic shower simulation
$v_{1,2}(p_T)$, Au+Au, $\sqrt{s_{NN}} = 11$ GeV

Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation.
$v_{1,2}(p_T)$, Au+Au, $\sqrt{s_{NN}} = 5$ GeV

...and elliptic flow results after reconstruction and resolution correction are consistent to that of...
$v_{1,2}(y)$, Au+Au, $\sqrt{s_{NN}} = 11$ GeV

Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation.
$v_{1,2}(y)$, Au+Au, $\sqrt{s_{NN}} = 5$ GeV

Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation.