Status of the performance studies of anisotropic flow with MPD at NICA

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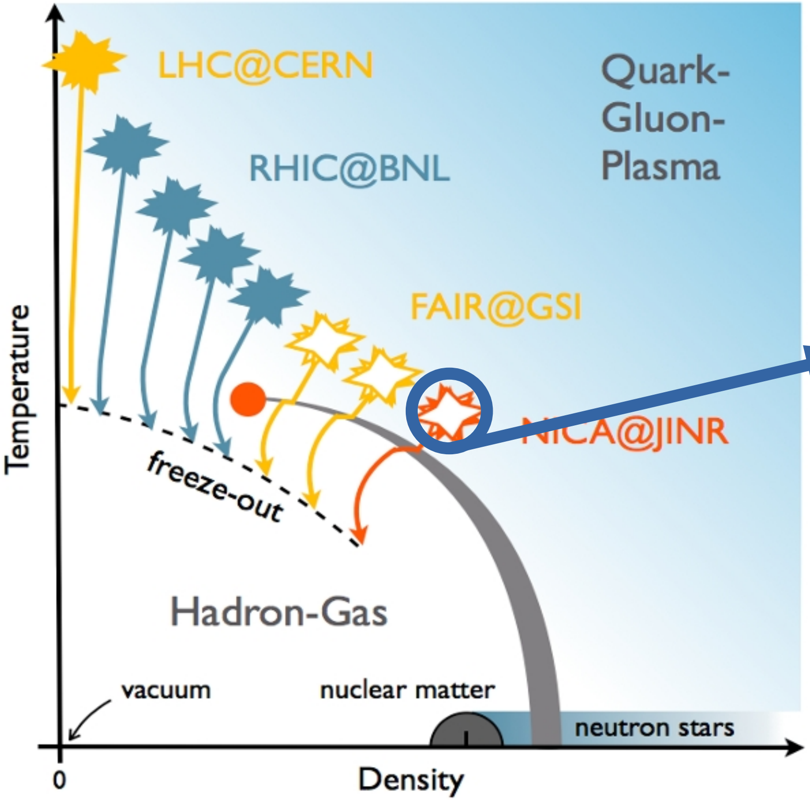
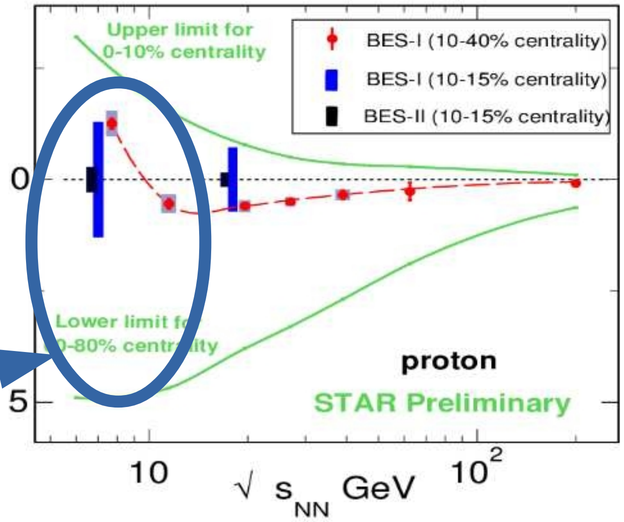
Directed flow at NICA energies $\sqrt{s_{NN}}$=2-11 GeV

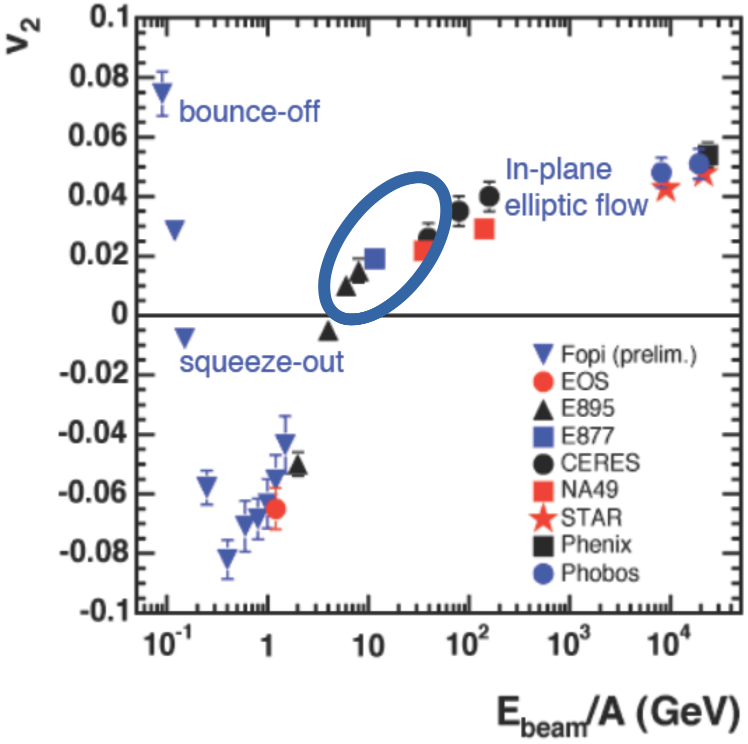


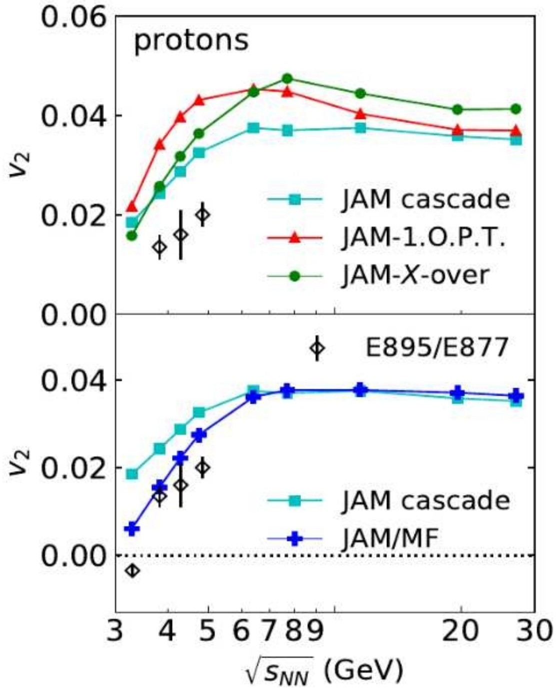


- Strong centrality dependence of directed flow of protons is expected at NICA energy range based on STAR preliminary data

- Non-monotonic dv_1/dy behavior can be signal of the first order phase transition?

Elliptic flow at NICA energies $\sqrt{s_{NN}}$=2-11 GeV



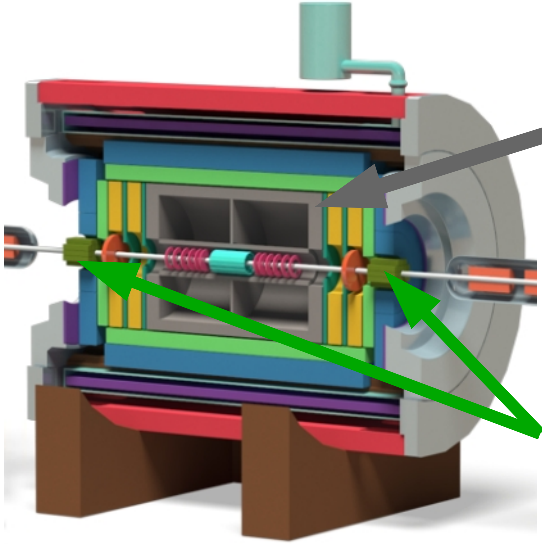


Nara, Yasushi et al. Eur.Phys.J. A54 (2018)

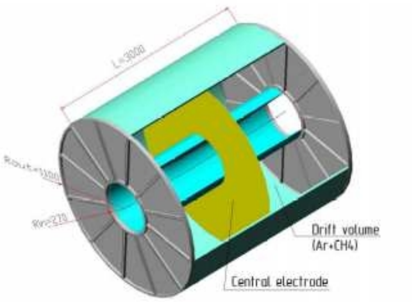
- At NICA energy range elliptic flow as a function of energy changes sign
- Both directed and elliptic flow are sensitive to the EoS (Equation of State)
- Large passing time → strong spectator influence on flow signal

Flow performance study at MPD (NICA)

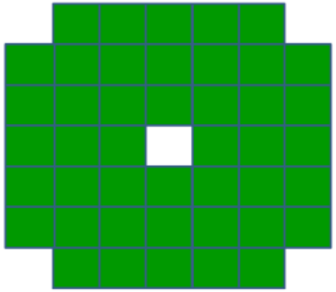
Multi Purpose Detector (MPD)



Time projection chamber (TPC)



Forward Hadron Calorimeter (FHCal)



EP plane

FHCal ($2<|\eta|<5$)

Time Projection Chamber (TPC)

- Tracking of charged particles within ($|\eta| < 1.5$, 2π in φ)
- PID at low momenta

Time of Flight (TOF)

- PID at high momenta

$-5<\eta<-2$	$-1.5<\eta<1.5$	$2<\eta<5$
FHCal	TPC $0.2<p_T<3$ GeV/c	FHCal

Setup, event and track selection

UrQMD
LAQGSM → GEANT4 → Reconstruction → Flow analysis

- Au+Au, $N_{events} = 4{\cdot}10^6$
- $\sqrt{s_{NN}}$ = 5 GeV
- $\sqrt{s_{NN}}$ =11 GeV

- TPC
- FHCal
- TOF
- ...

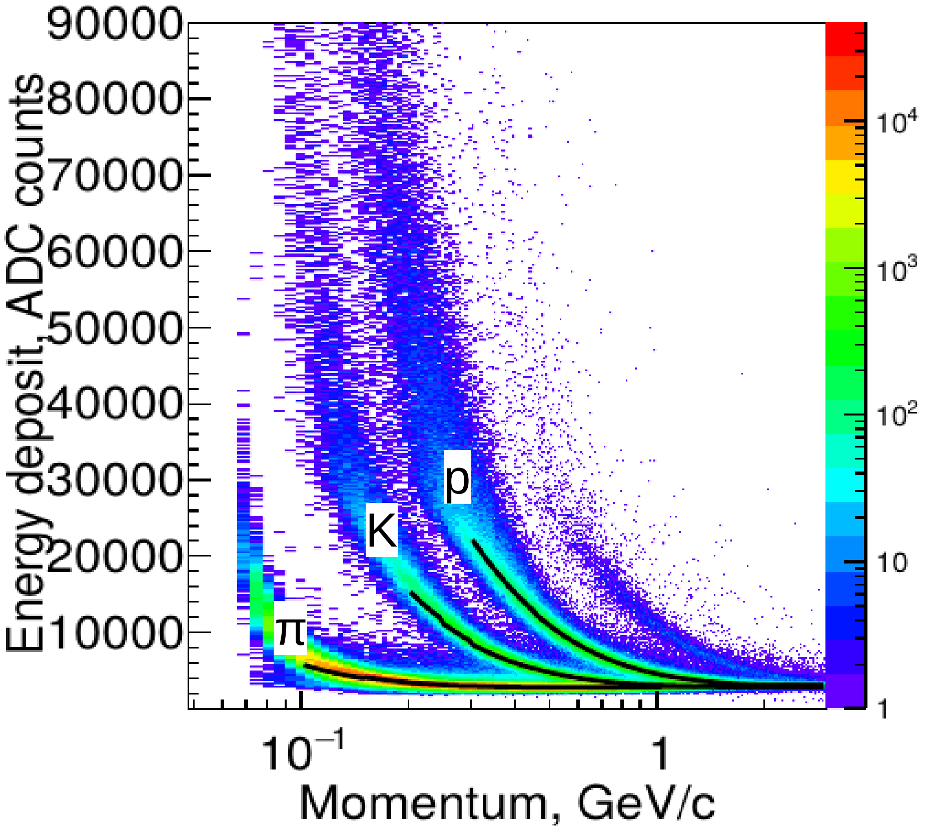
Event classification:
- Track multiplicity
- FHCal energy

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

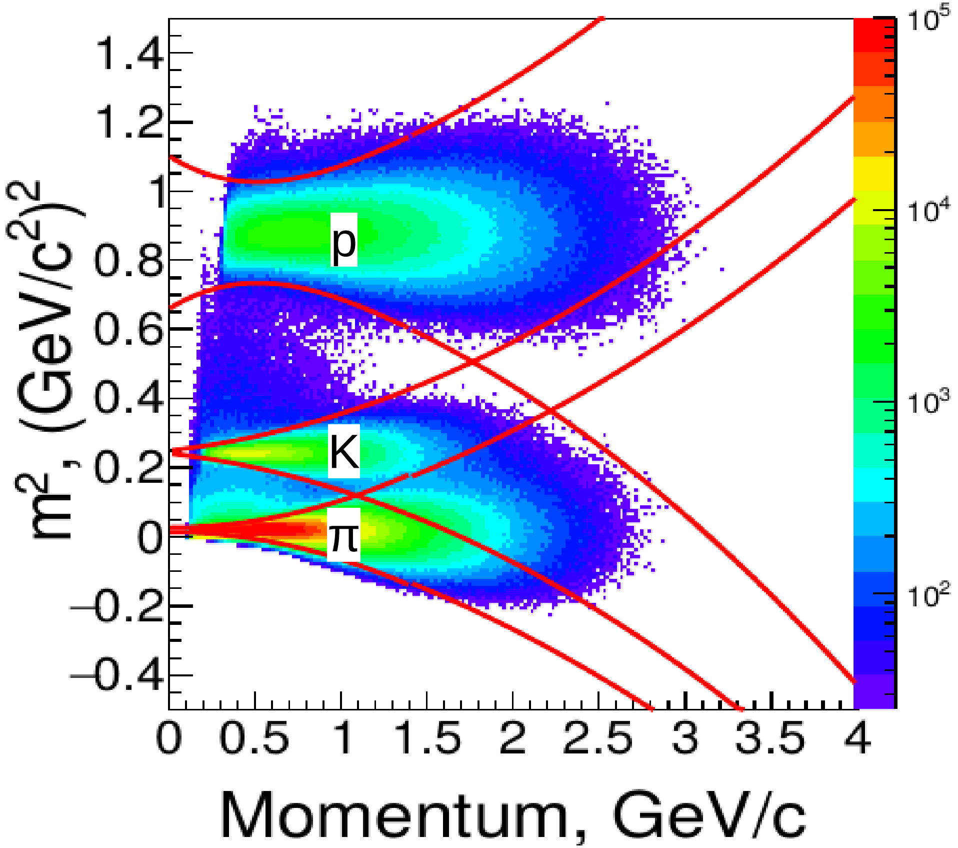
MPDRoot, June 2018

http://mpd.jinr.ru/wp-content/uploads/2018/05/MPD_TDR_FHCal_28_05_2018.pdf

Particle identification based on TPC + TOF

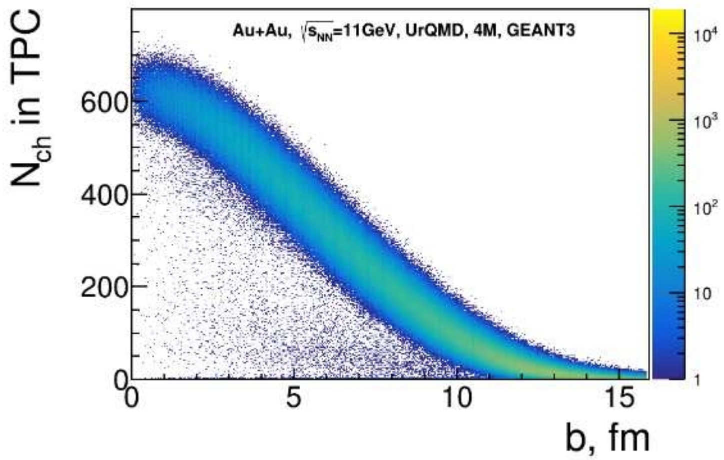


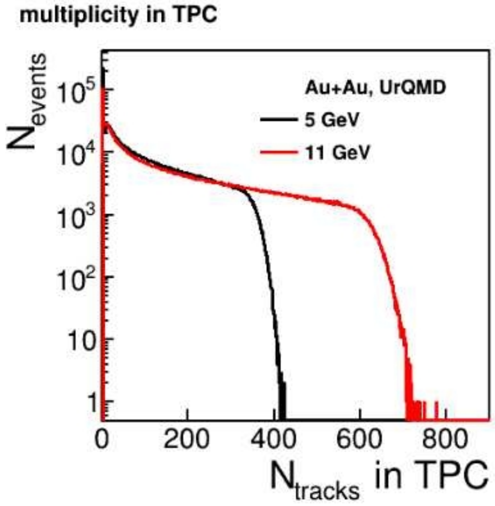
Low momentum:
dE/dx from TPC

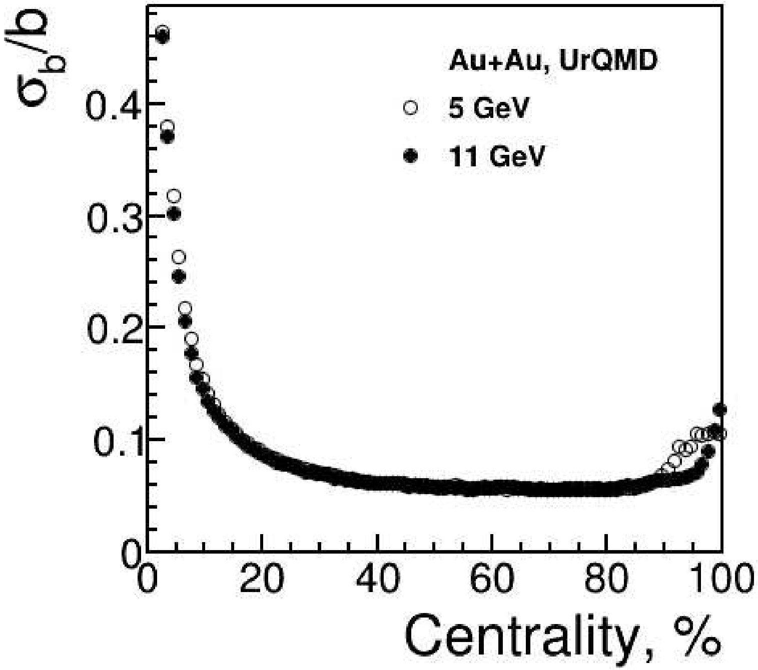


High momentum:
m^2 estimated from TOF signal

Centrality estimation using multiplicity of charged particles in TPC





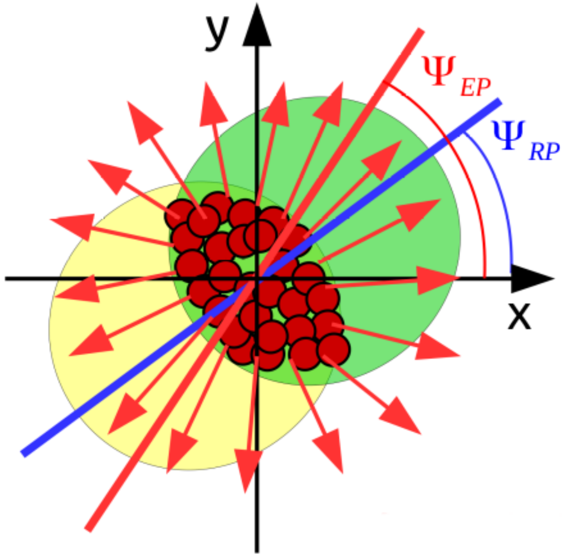


- Good correlation between *b* and TPC Multiplicity
- Events were grouped in centrality classes based on multiplicity distribution

Impact parameter resolution is 5-10% for ~10-80% centrality range

Event plane method

- Reaction plane is not known experimentally
- Finite number of detected particles leads to limited resolution of the event plane orientation
- Azimuthal angle of the event plane can be estimated from azimuthal angles of emitted particles:



$$\vec{Q}=\{Q_x, Q_y\}$$

$$Q_{n,X}=\sum_i \omega_i \cos(n\varphi_i)=|\vec{Q}|\cos(n\Psi_n^{EP})$$

$$Q_{n,Y}=\sum_i \omega_i \sin(n\varphi_i)=|\vec{Q}|\sin(n\Psi_n^{EP})$$

$$i=0\ldots N_{particles}$$

$$\Psi_n^{EP}=\frac{1}{n}\tan^{-1}\left(\frac{Q_{n,Y}}{Q_{n,X}}\right)$$

$$v_n=\frac{\langle\cos(n(\varphi-\Psi_{n,EP}))\rangle}{R_{n,EP}}$$

$$R_{n,EP}=\langle\cos(n(\Psi_{n,EP}-\Psi_{RP}))\rangle$$

$R_{n,EP}-$ Resolution correction factor

Event plane method implementation in MPD (NICA)

Both left and right FHCal parts were used:

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

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

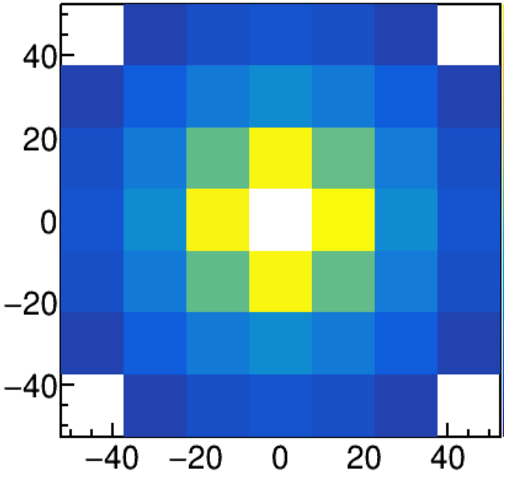
$$m = 1 \text{ was used}$$

- E_i is the energy deposition in *i-th* FHCal module
- φ_i is its azimuthal angle.
- For *m=1* weights had different signs for backward and forward rapidity.

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

$$Res_m\{\Psi_n^{EP,true}\} = \langle \cos[n(\Psi_{RP} - \Psi_n^{EP})] \rangle$$

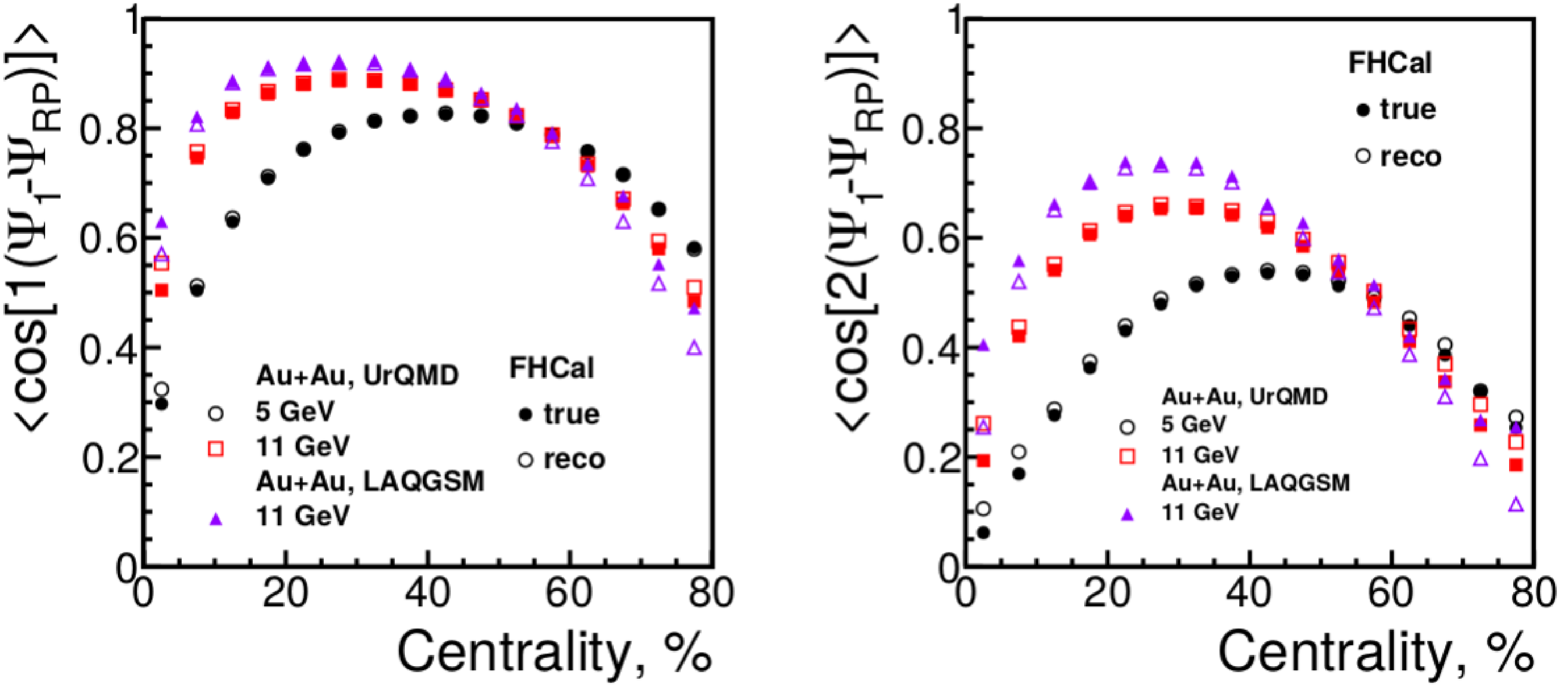
$$v_n = \frac{\langle \cos[n(\Psi_{RP} - \Psi_n^{EP})] \rangle}{Res_m\{\Psi_n^{EP,true}\}}$$



Energy distribution in FHCal

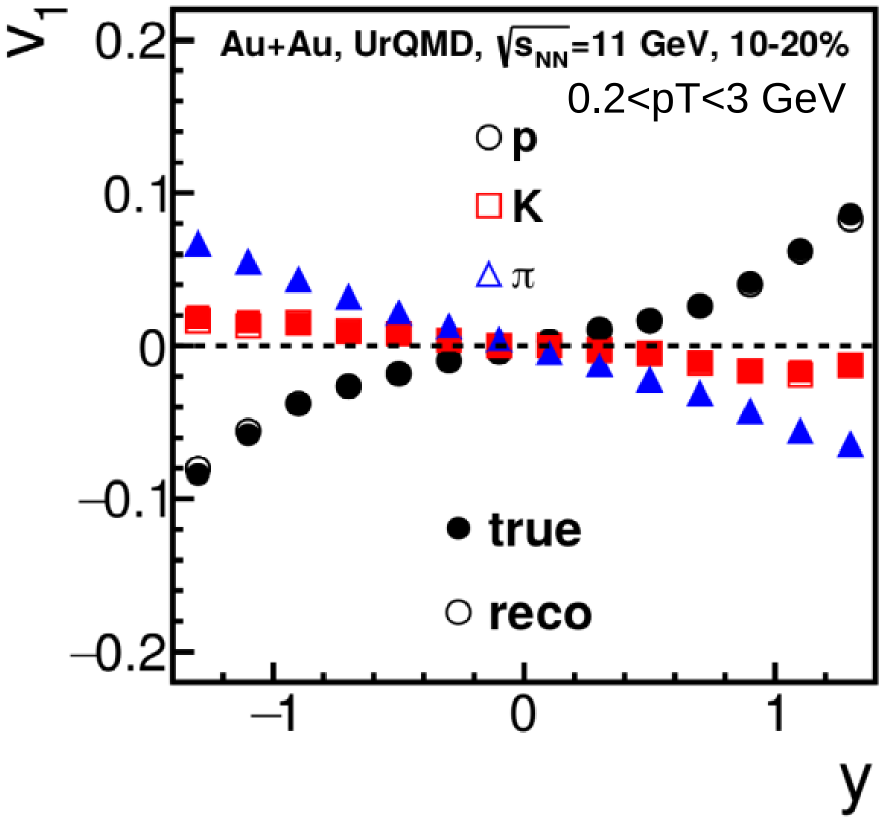
Δη-gap>0.5 between TPC and FHCal suppresses non-flow contribution

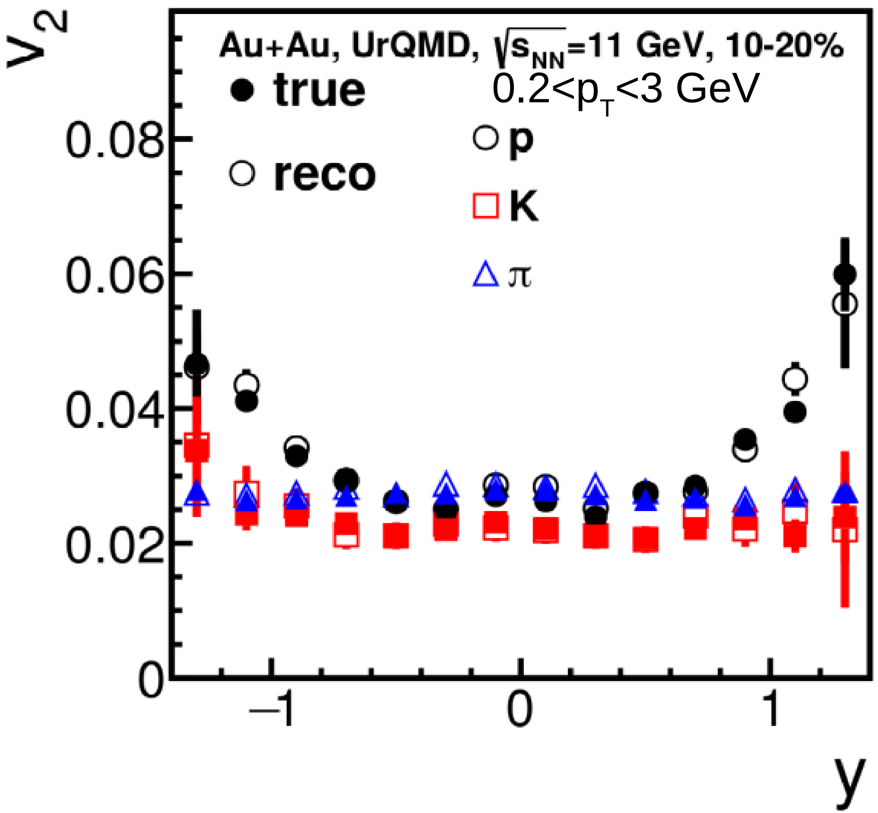
Event plane resolution correction factors



Good performance in the centrality range 0-80% for NICA collision energy range

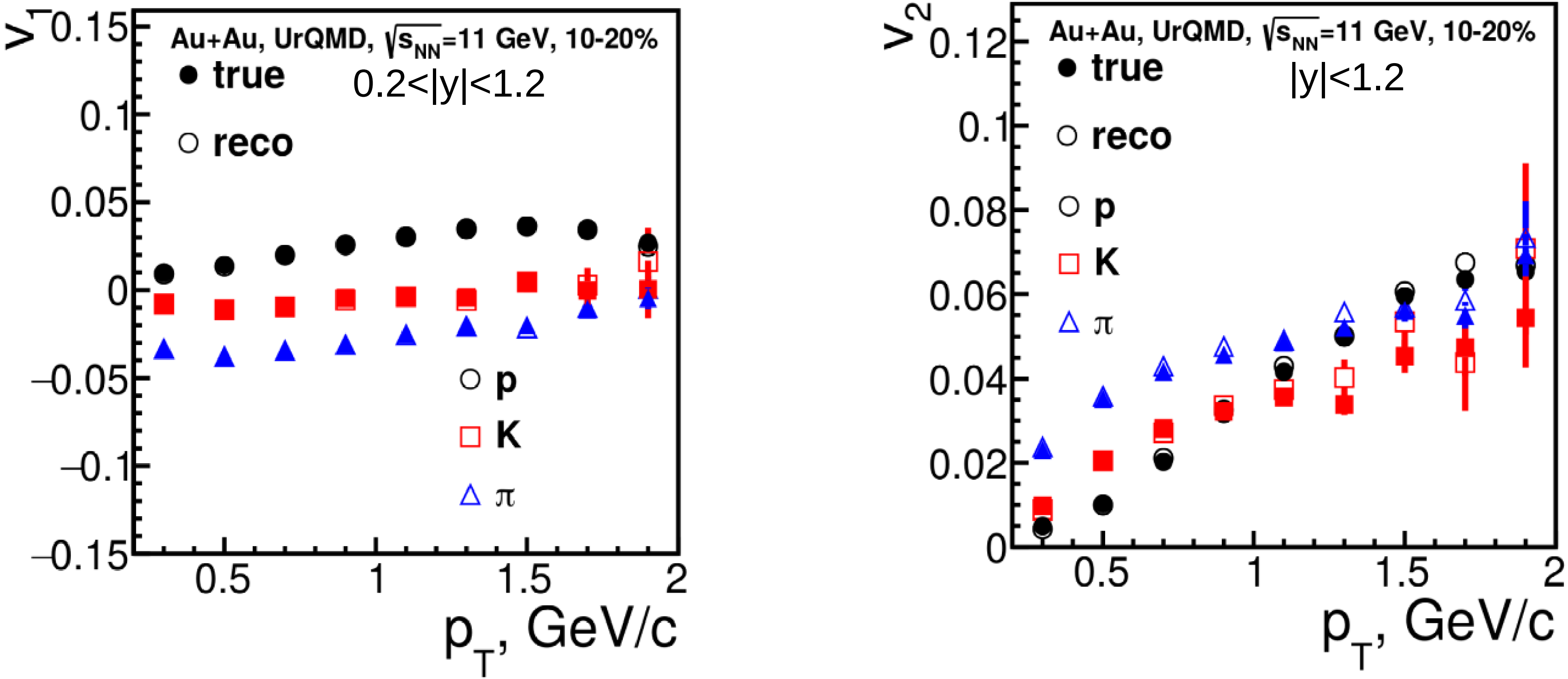
y-dependence of v_1 and v_2 of the reconstructed signal





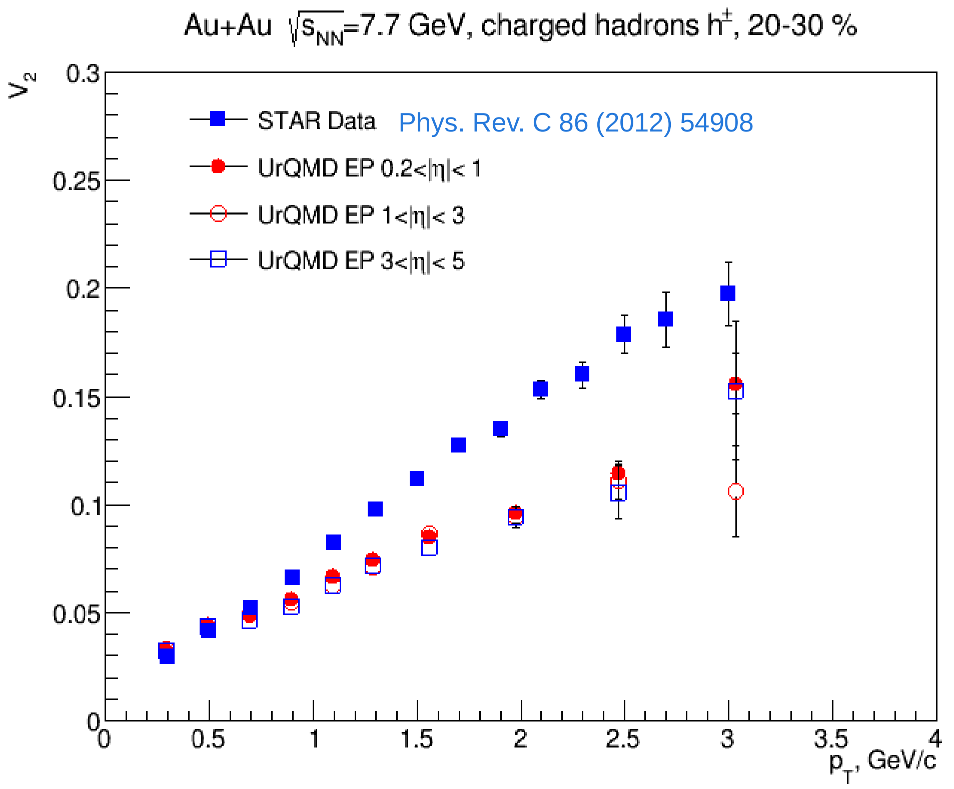
Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

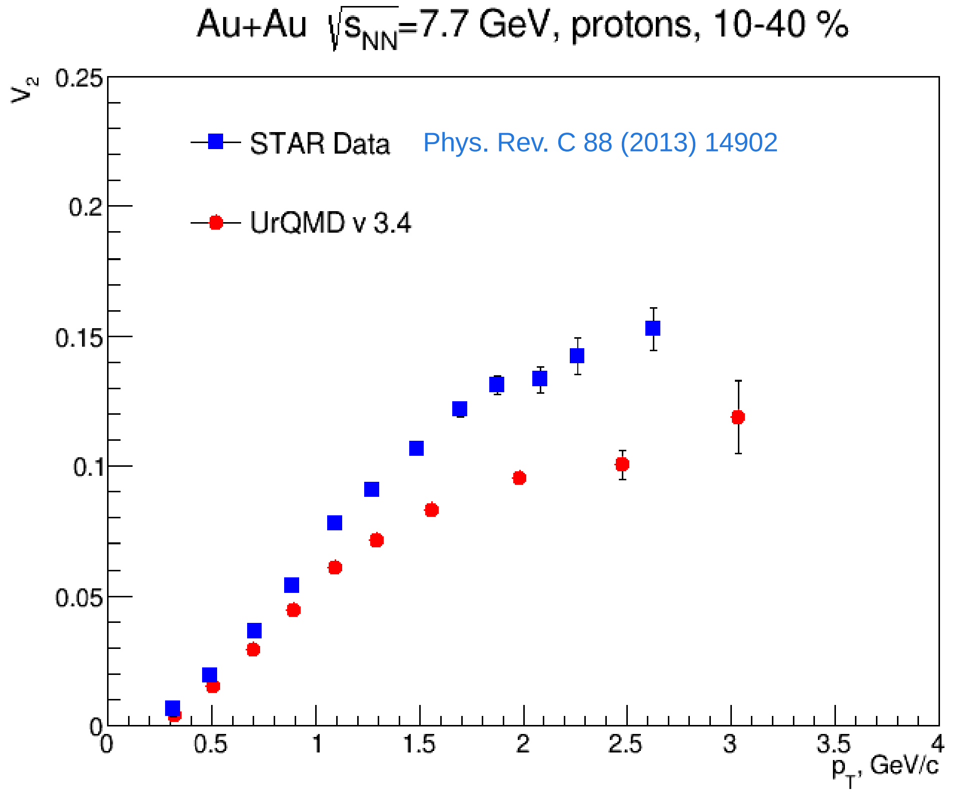
p_T-dependence of v_1 and v_2 of reconstructed signal



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

BES: differential elliptic flow: UrQMD

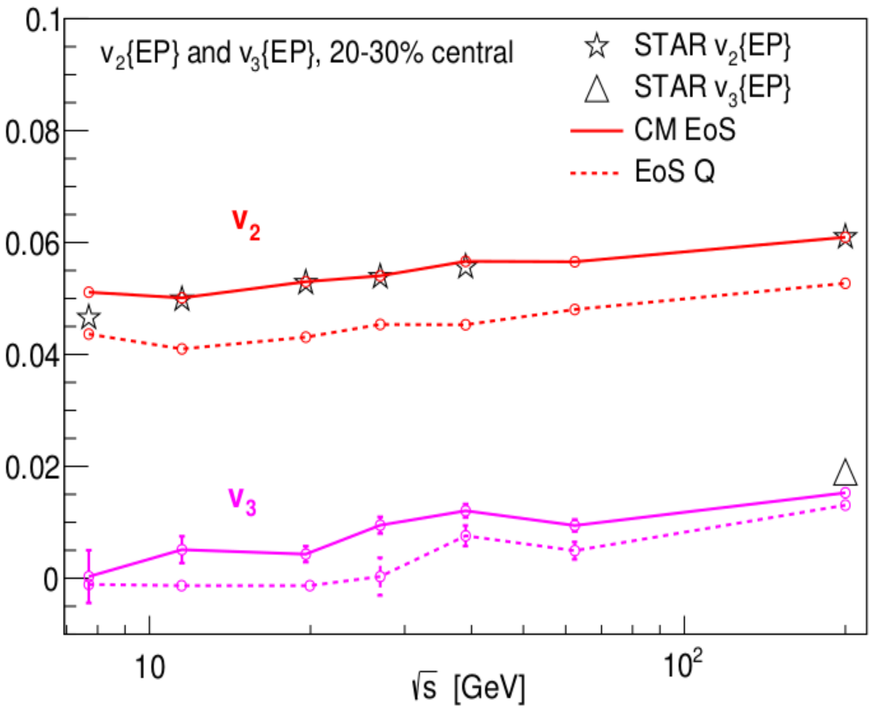


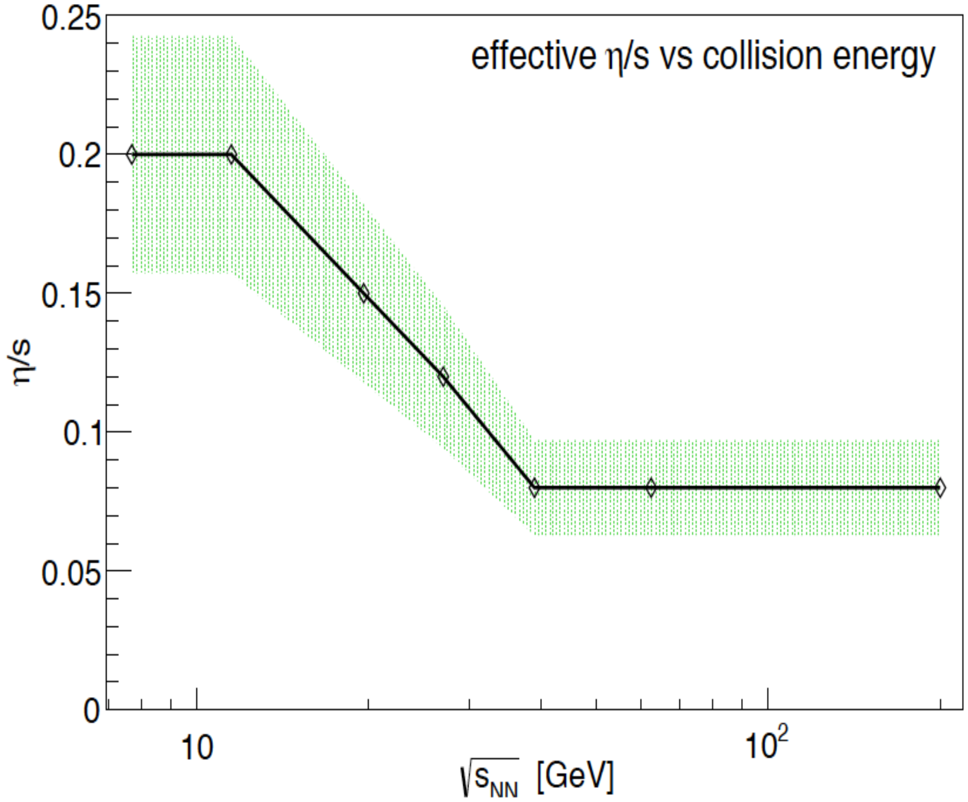


What about other “hadronic” models: SMASH, JAM, HSD? - Under investigation

Elliptic and triangular flow of charged hadrons at RHIC BES

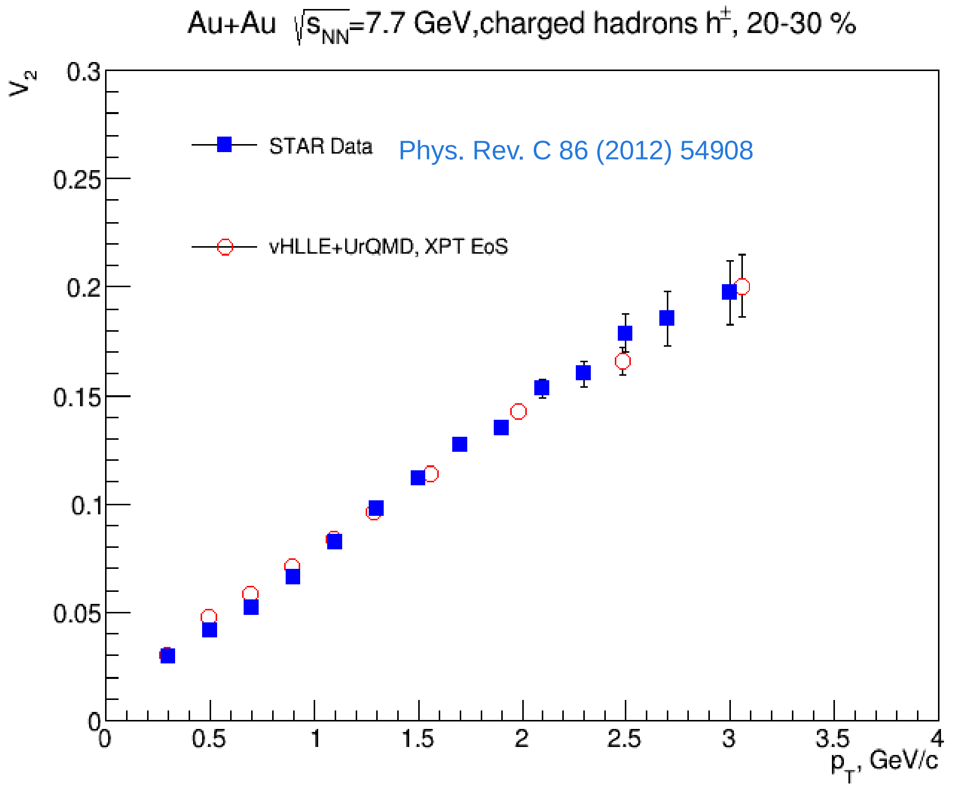
Iu.A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher, Phys.Rev. C91 (2015) no.6, 064901

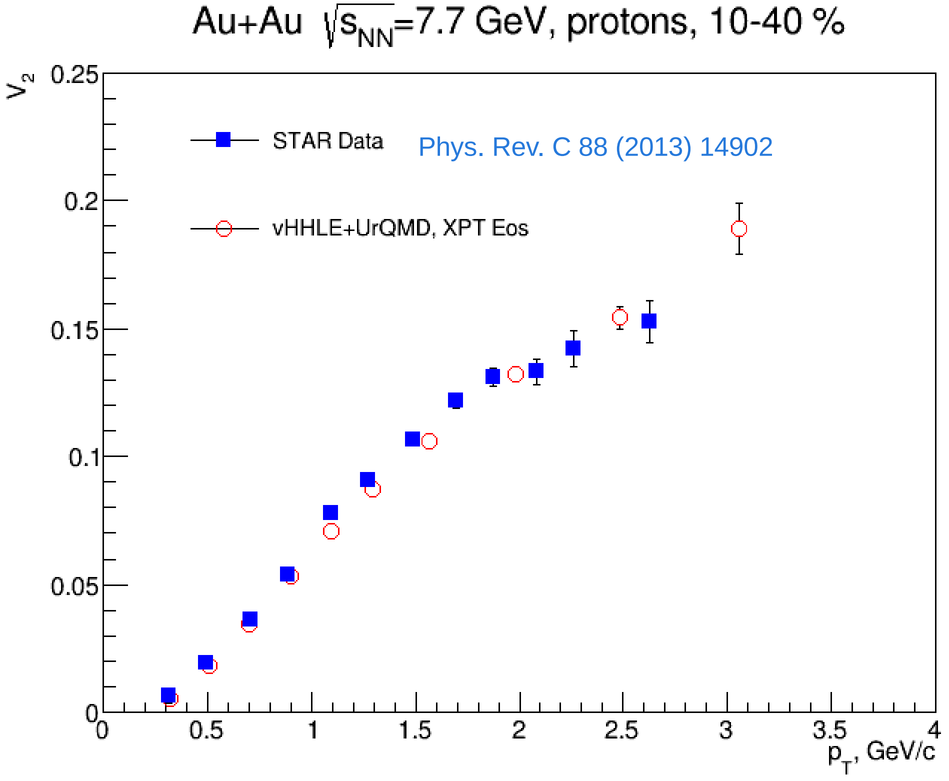




Hybrid model: UrQMD + 3D hydro model vHLLE + UrQMD
Shows good agreement with published STAR data for integrated $v_n(\sqrt{s_{NN}})$ from BES-I

Differential elliptic flow: 3D hydro vHLLE + UrQMD



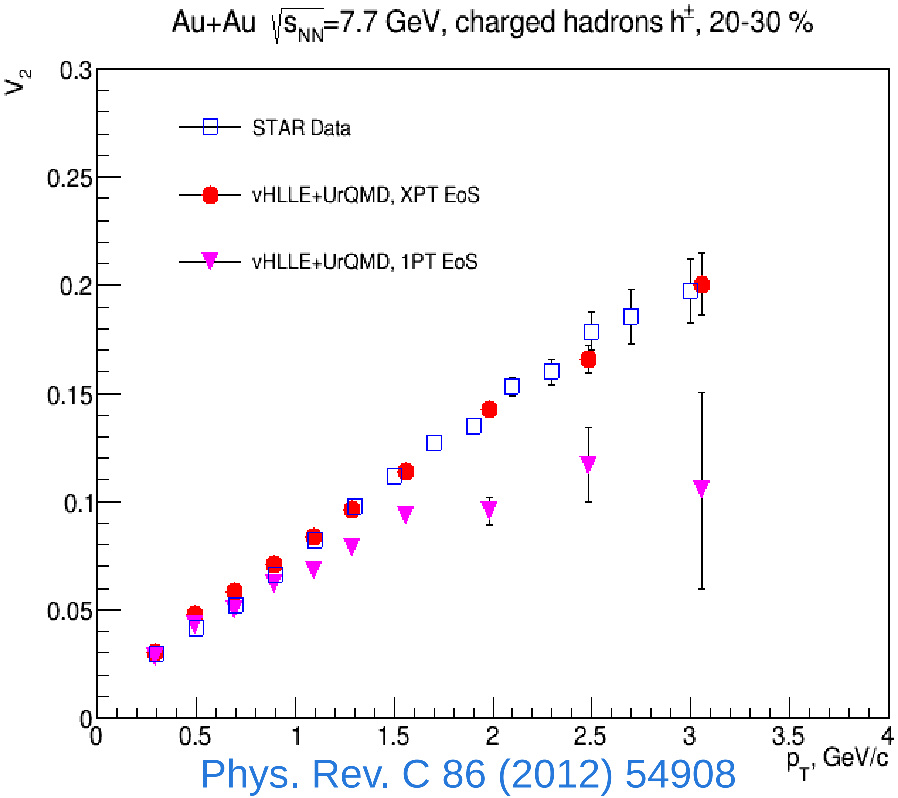


3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

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

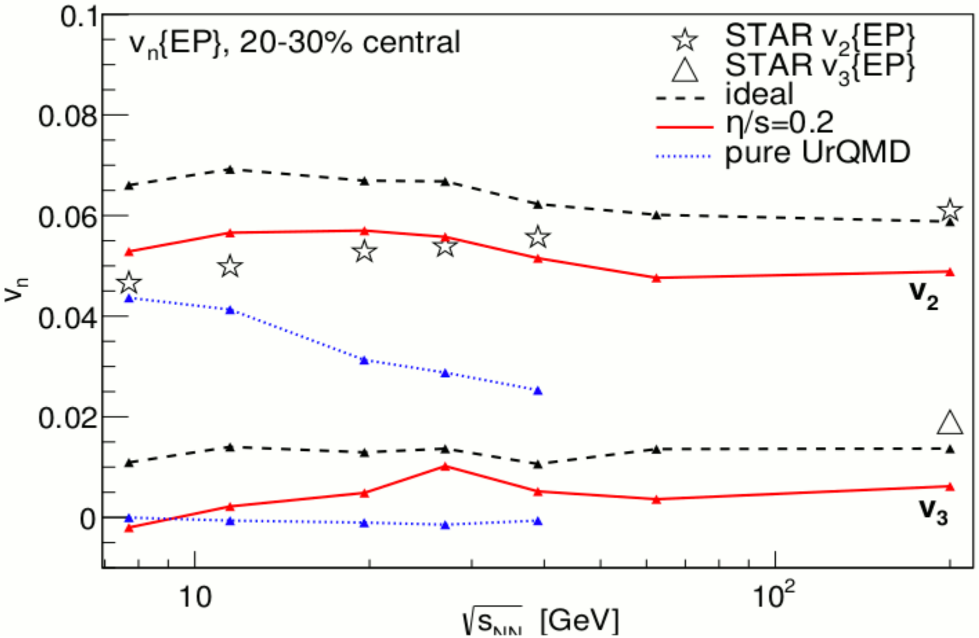
Good agreement with STAR published data

Differential elliptic flow: 3D hydro vHLLE + UrQMD



Phys. Rev. C 86 (2012) 54908

Iu.A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher, Phys.Rev. C91 (2015) no.6, 064901



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)

Summary

Anisotropic flow performance study in MPD (NICA):

- Full reconstruction chain was implemented:
  - Combined particle identification based on TPC and TOF
  - Realistic hadronic simulation (GEANT4)
- Reconstructed v_1,v_2 are in agreement with MC generated data

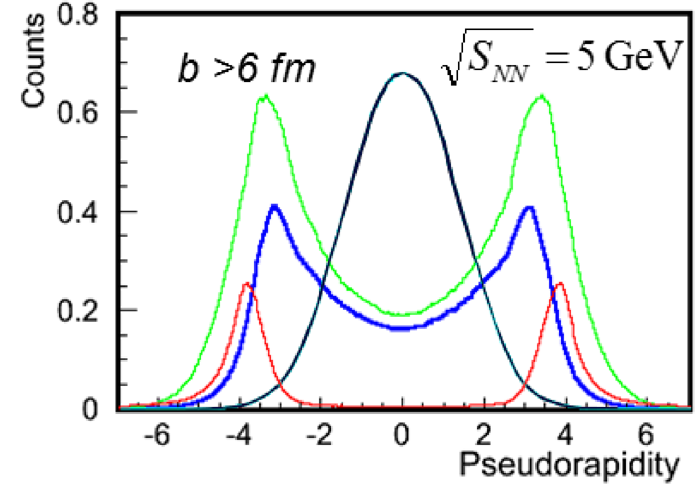
Model comparison:

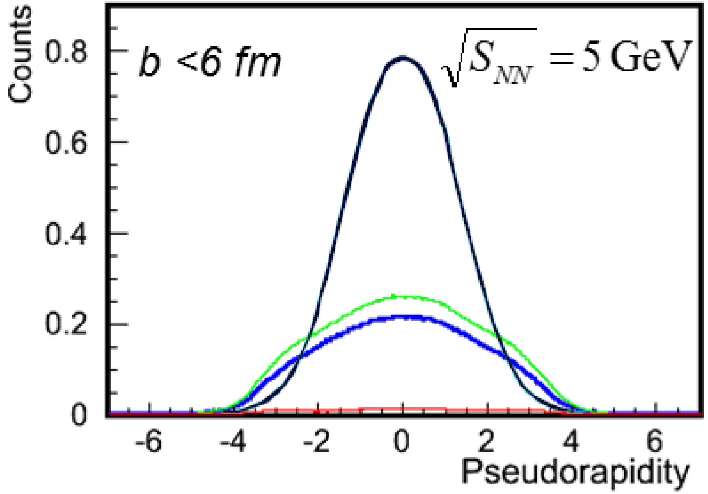
- Pure UrQMD gives smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV
- $v_2(p_T)$ from 3D hydro model vHLLE + UrQMD is in a good agreement with STAR data
- Elliptic and triangular flow are sensitive to the EoS (1PT or XPT)
- vHLLE + UrQMD will be used for the next step of the flow performance studies at MPD (NICA)

Thank you for your attention!

Backup

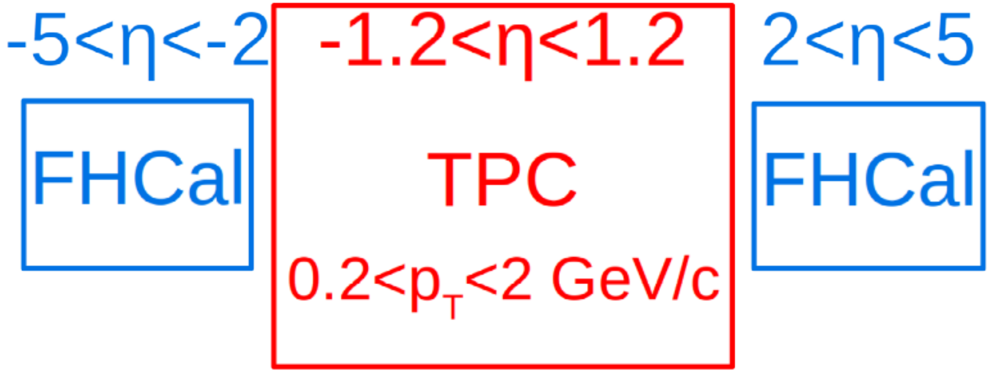
FHCal and TPC acceptance



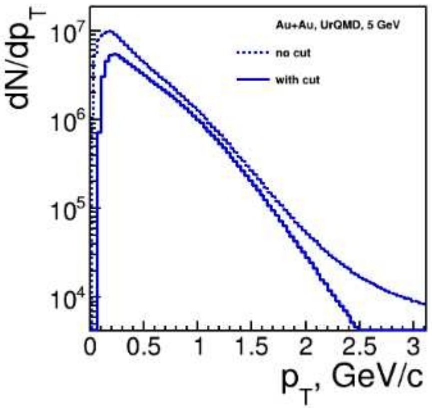


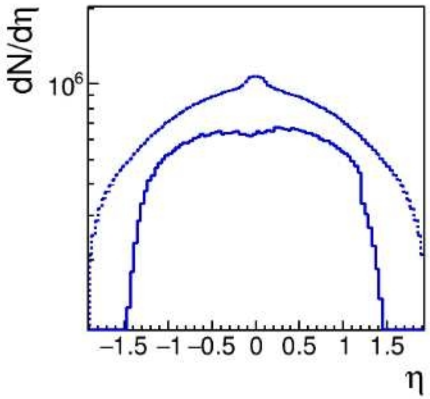
Pions
Neutrons
Protons
Fragments

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

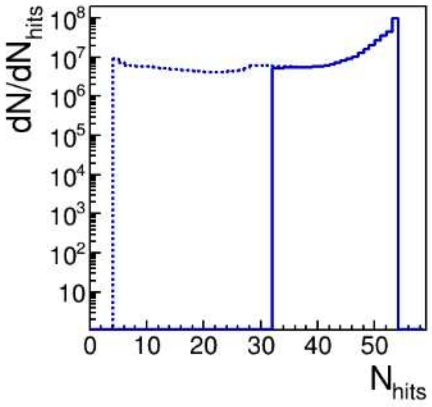


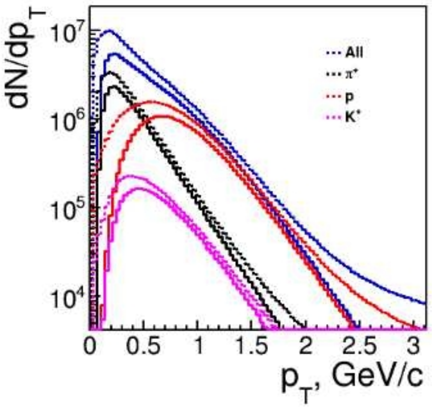
Track selection

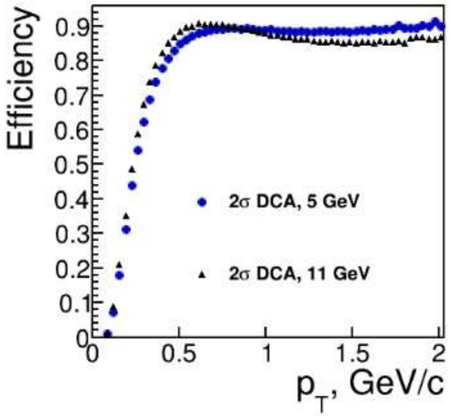




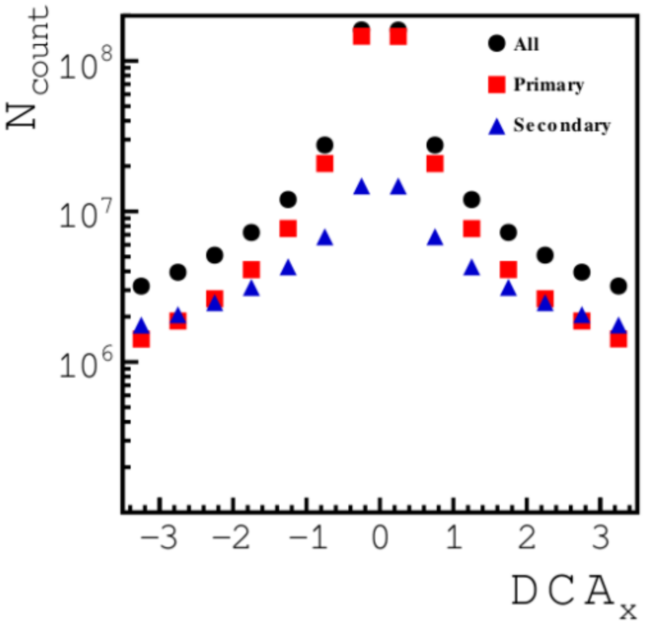
- $N_{TPC\ hits}$ >32
- $|p_T|<3$
- $|\eta|<1.5$
- PID based on TPC+TOF (MpdPid)

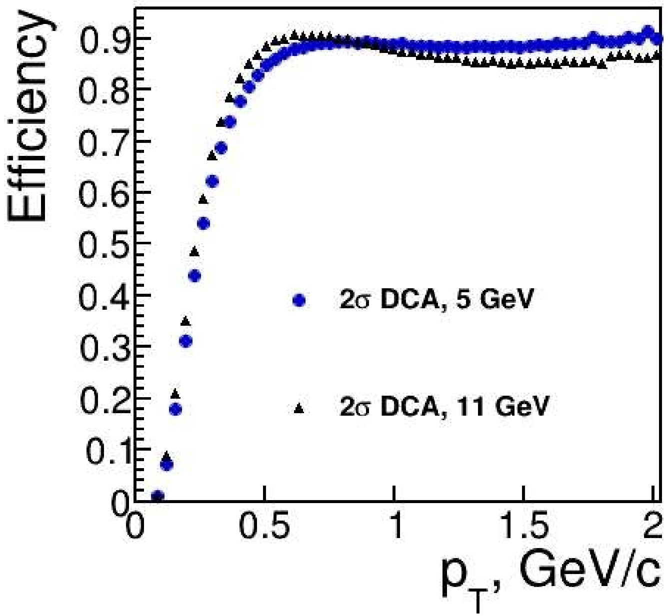






Primary track selection



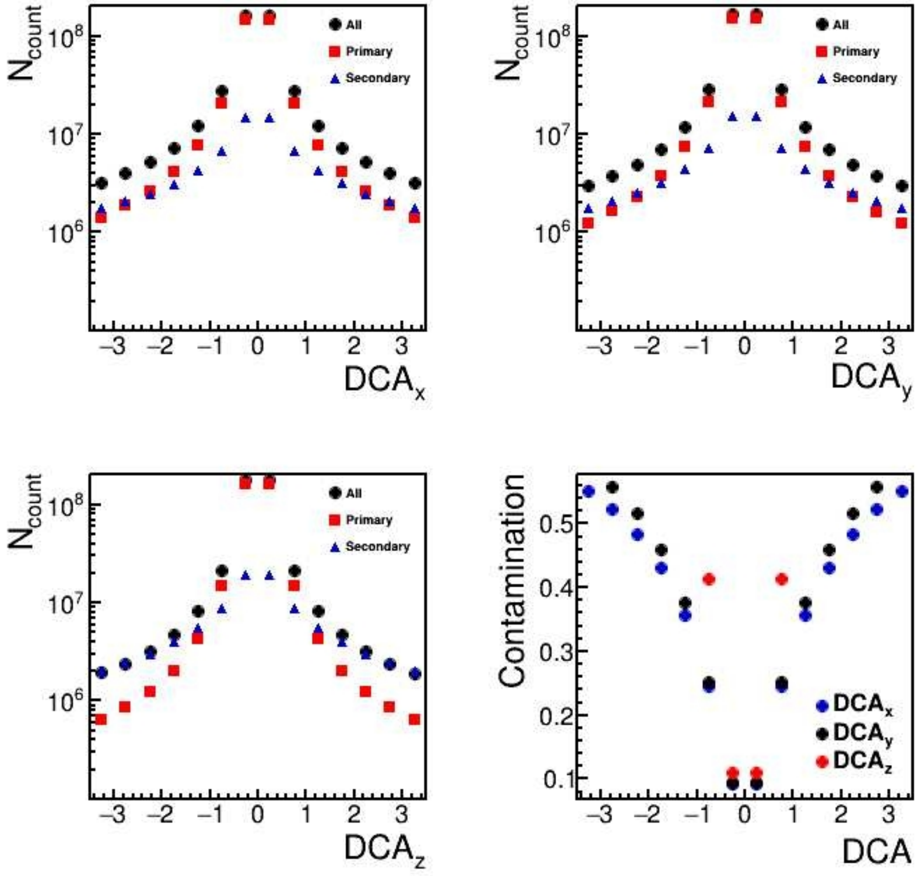


Distance of the closest approach (DCA) between TPC tracks and primary vertex

Tracks from secondary particles distort measured azimuthal flow coefficients

Introduced p_T and η dependent 2σ DCA cut from Gaussian fit with smoothened p_T dependence to second particle contamination

Primary track selection

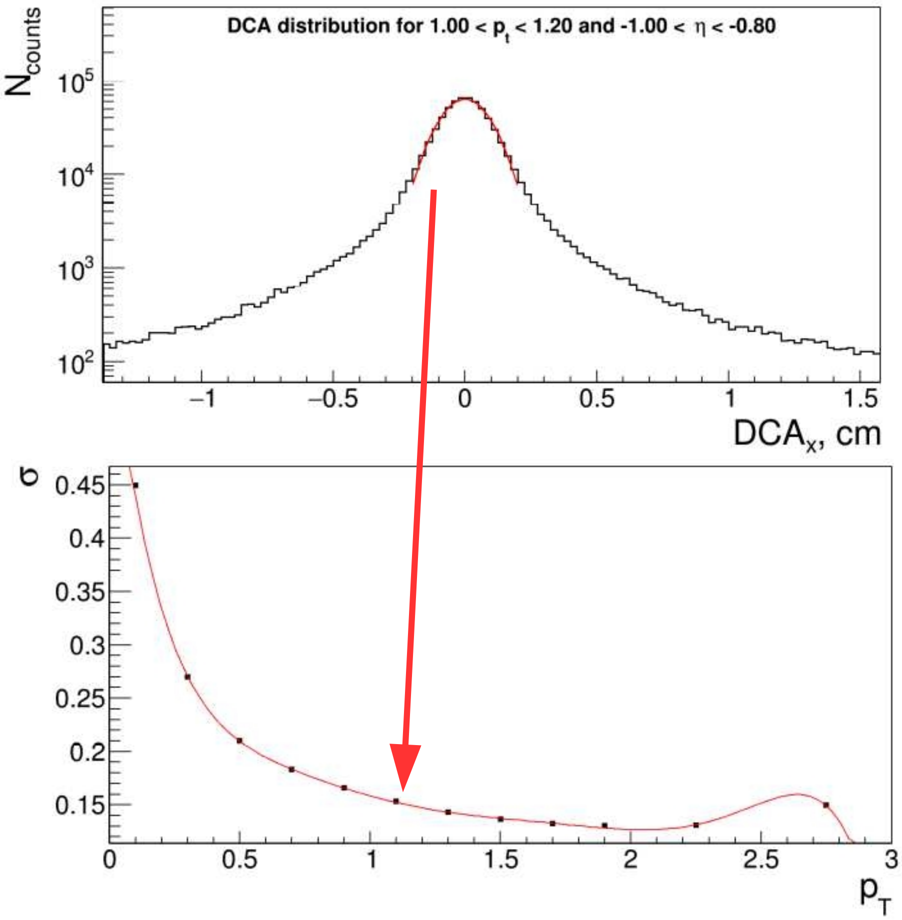


Distance of the closest approach (DCA) between TPC tracks and primary vertex

Tracks from secondary particles distort measured azimuthal flow coefficients

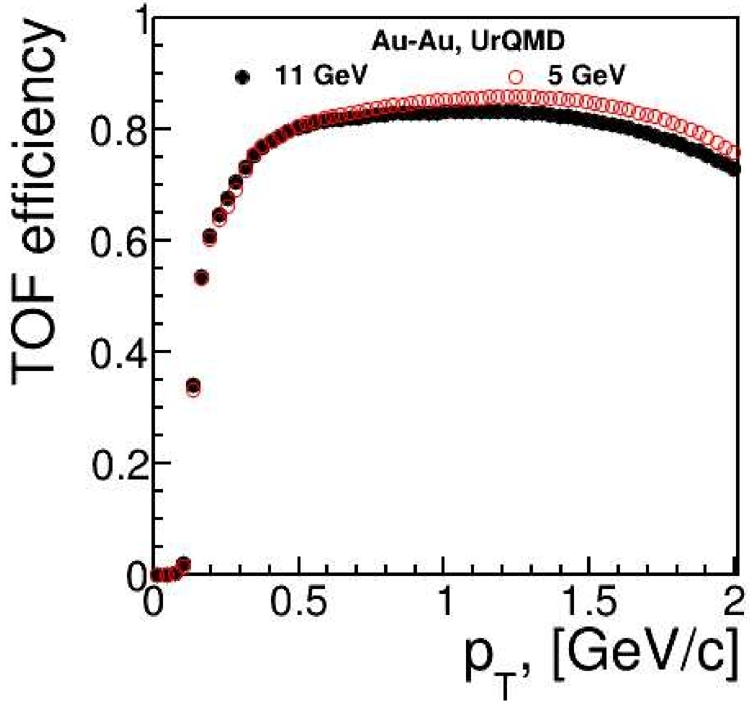
Introduced p T and η dependent 2σ DCA cut from Gaussian fit with smoothened p T dependence to reduce secondary contamination

Primary track selection: 2σ cut



- Peak of the DCA distribution was fitted using gaus fit;
- σ given from that fit as function of p_T was fitted using polynomial fit.
- Fitted polynomial function (*Pol*) was used for primary track selection: $|DCA|<2Pol(p_T)$.

PID implementation in the performance study

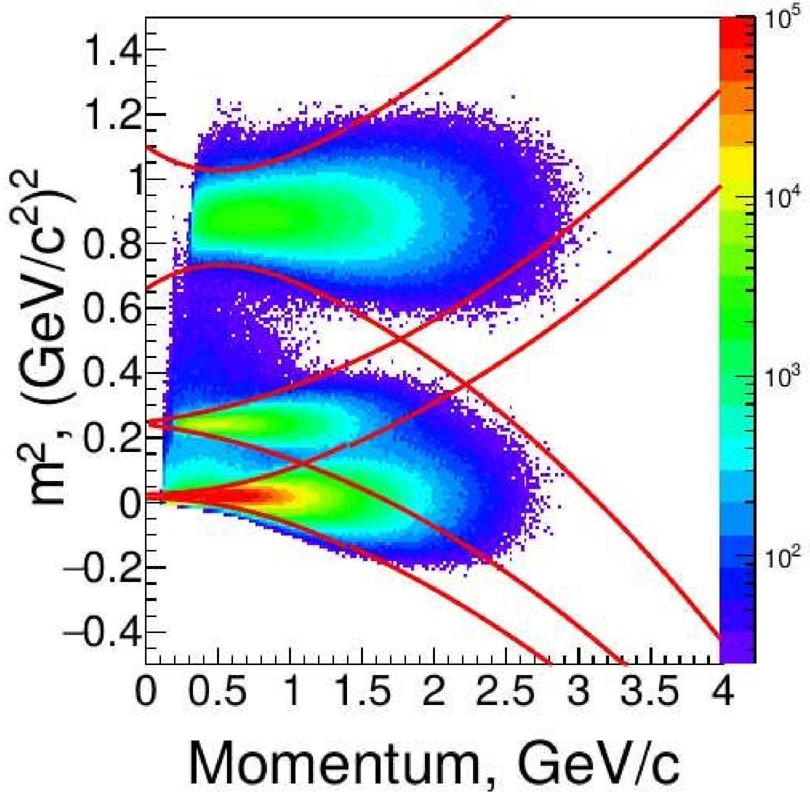


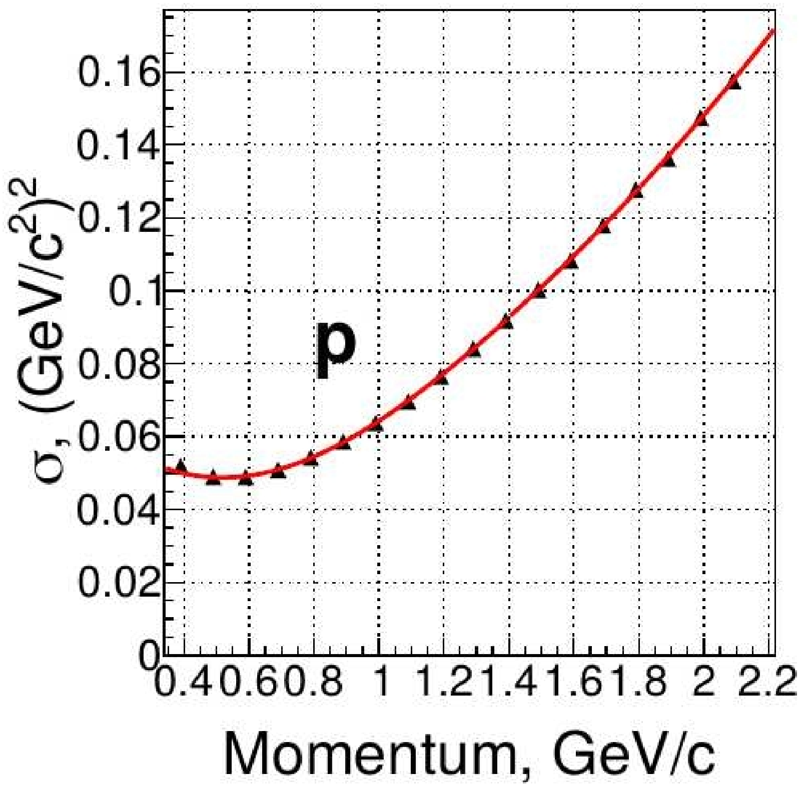
Only tracks with TOF hit were selected

MpdPid method returns probability of the track to be the certain particle species

Only tracks with corresponding particle probability $P_{particle}$>90% were selected

Particle identification using TOF

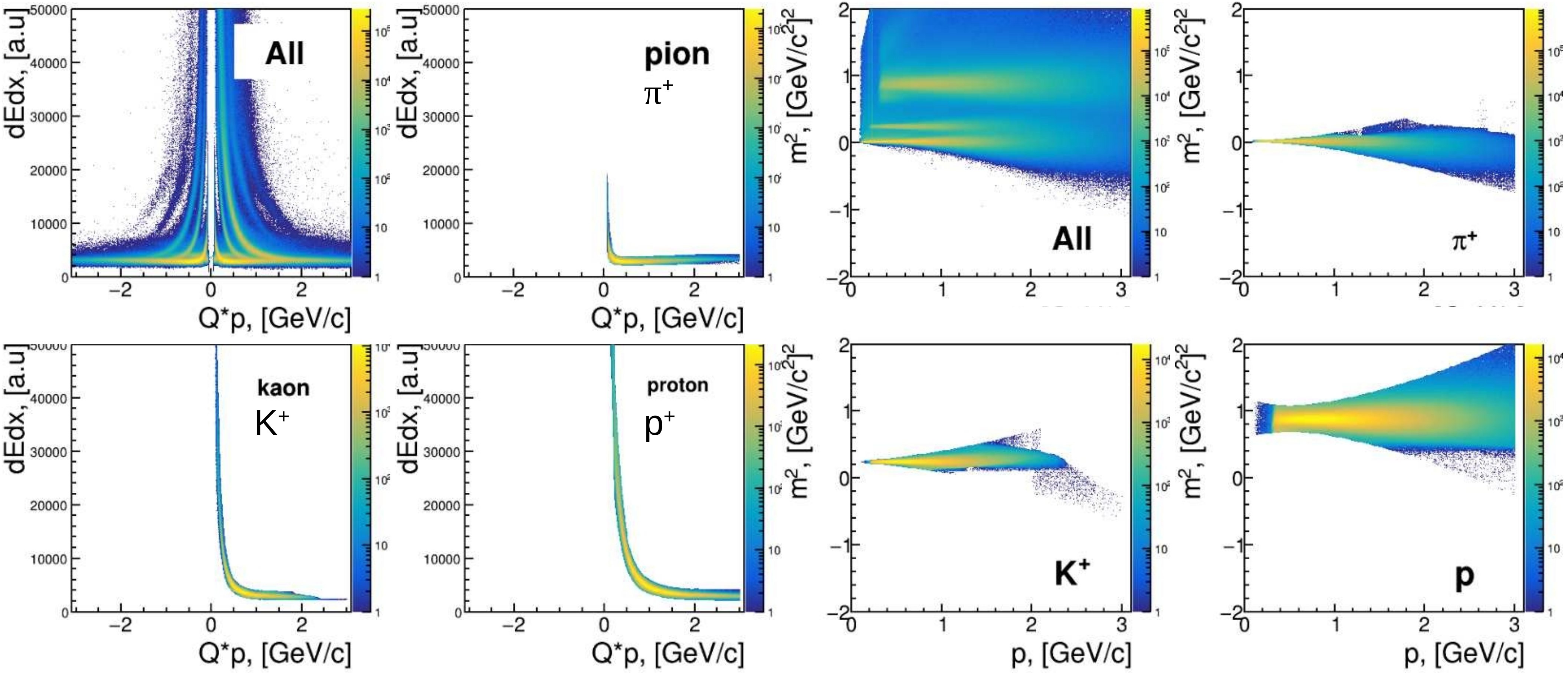




TOF identification significantly improves PID results in the high momenta region (p>1 GeV/c). It is based on the separation by the m^2 values.

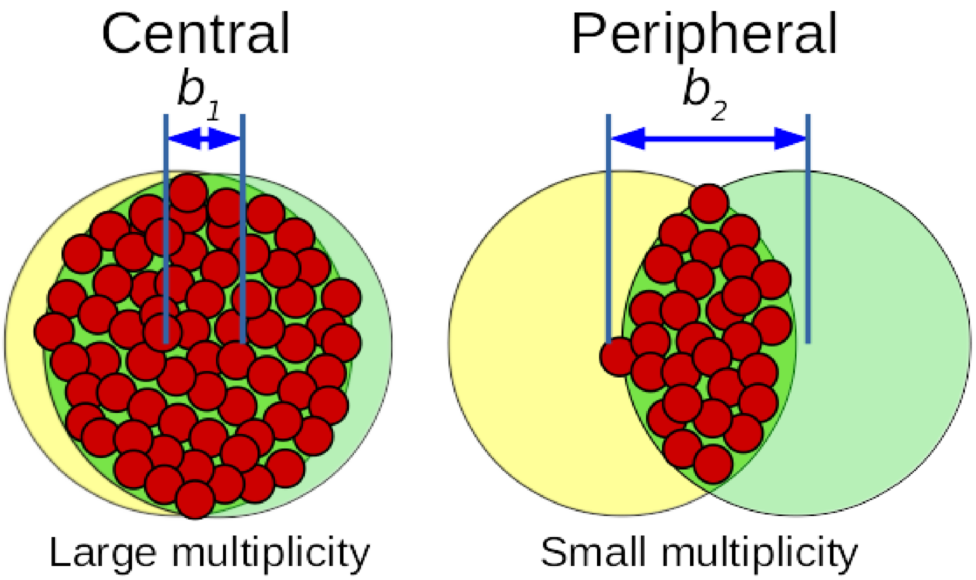
Red lines on this figure show 3σ bands for pions, kaons and protons.

PID implementation in the performance study



Centrality determination

Centrality determination



Impact parameter is not known

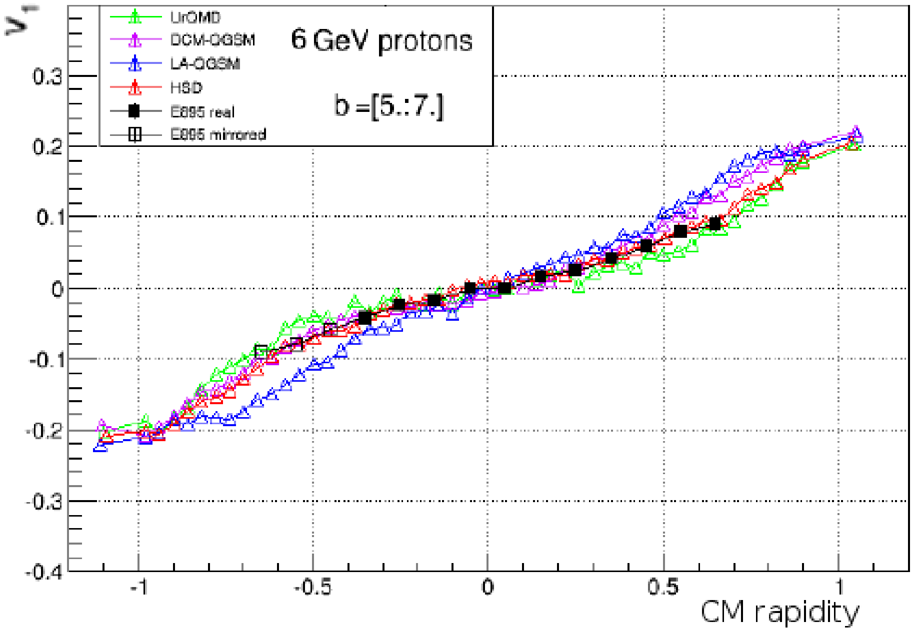
Experimentally:

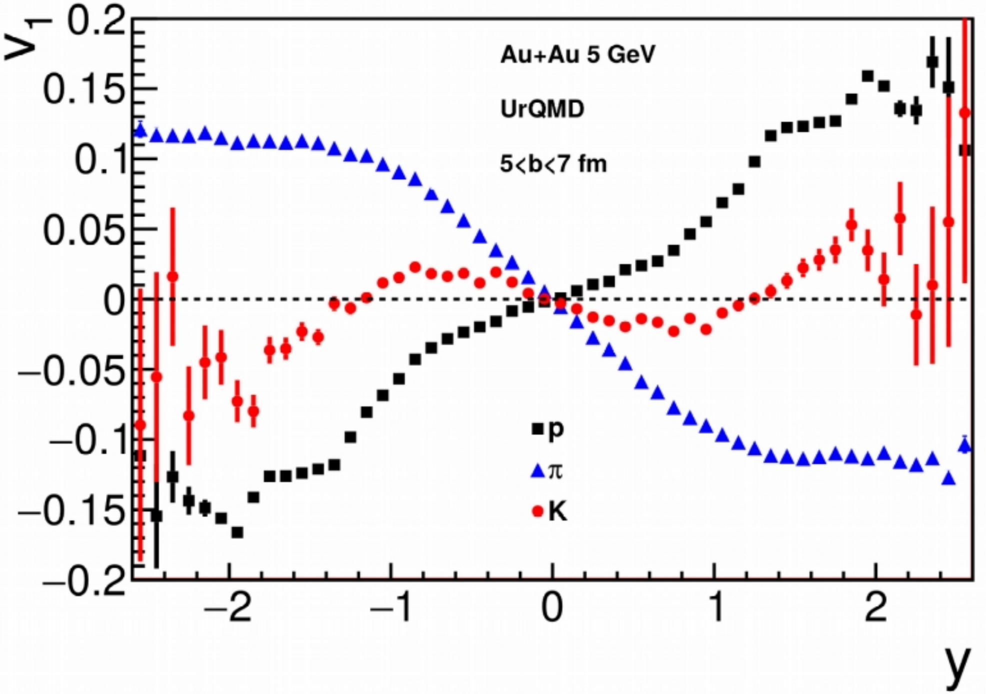
Centrality classes determined based on a fraction of a total number of nucleus-nucleus inelastic collisions

Multiplicity of the produced particles and/or spectator’s energy can be used for centrality determination

Anisotropic flow study

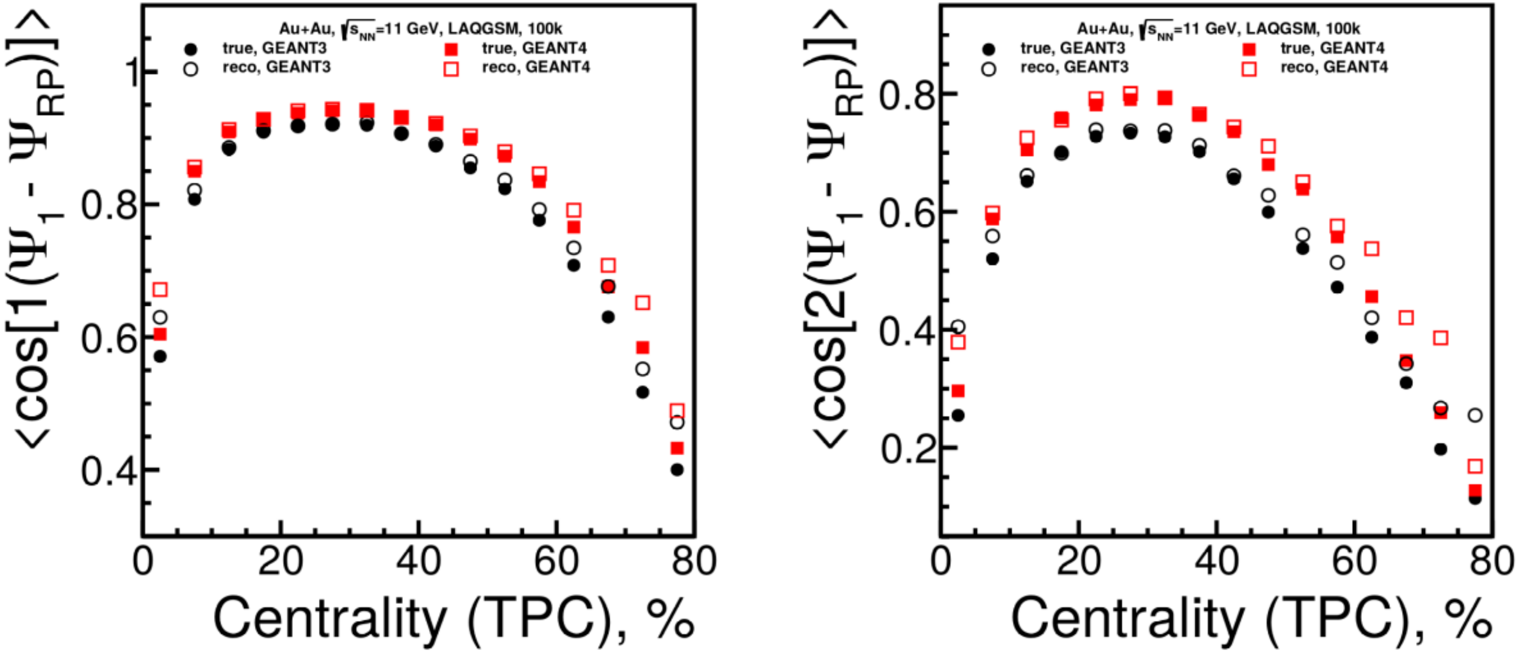
Modeling directed flow at NICA energies





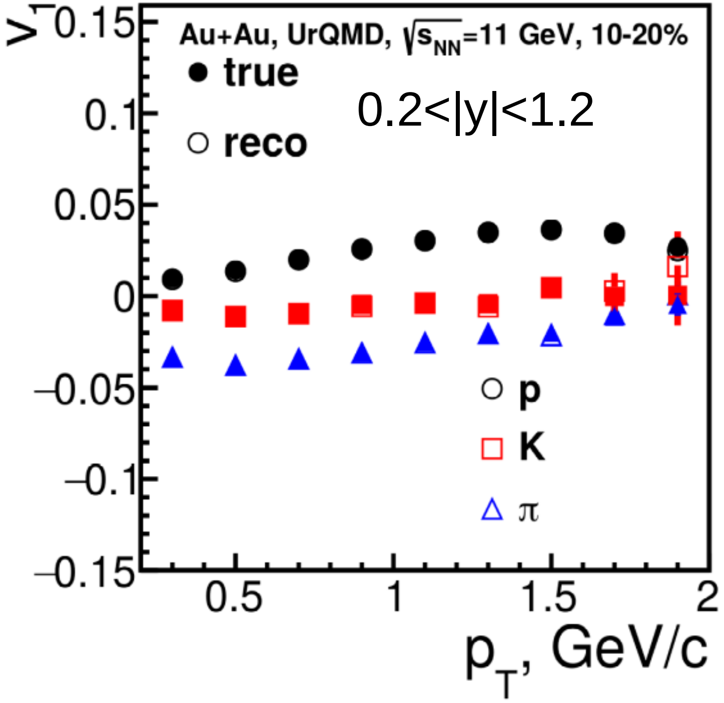
Both UrQMD and LAQGSM are in agreement with experimental measurements.
For performance study UrQMD and LAQGSM are used.

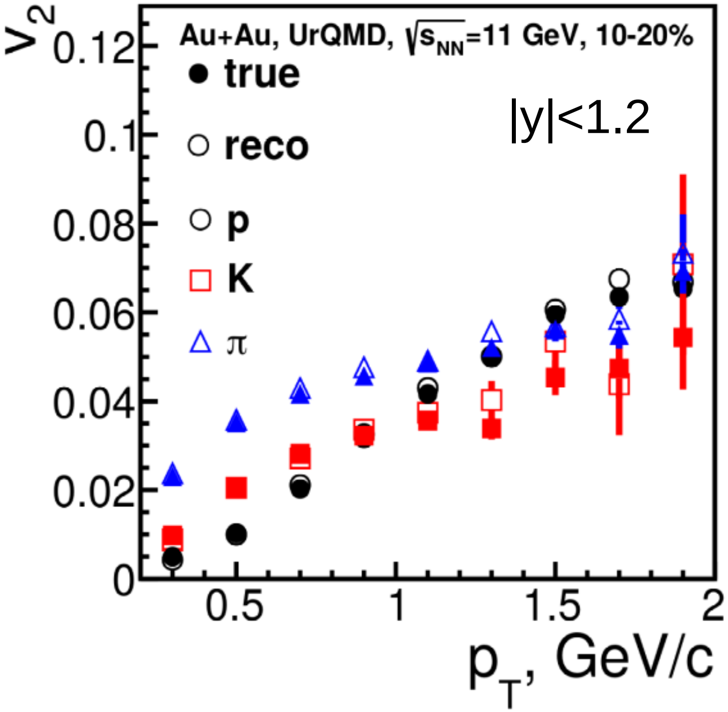
Resolution correction factor: GEANT3 vs GEANT4 comparison



GEANT4 has more realistic hadronic shower simulation

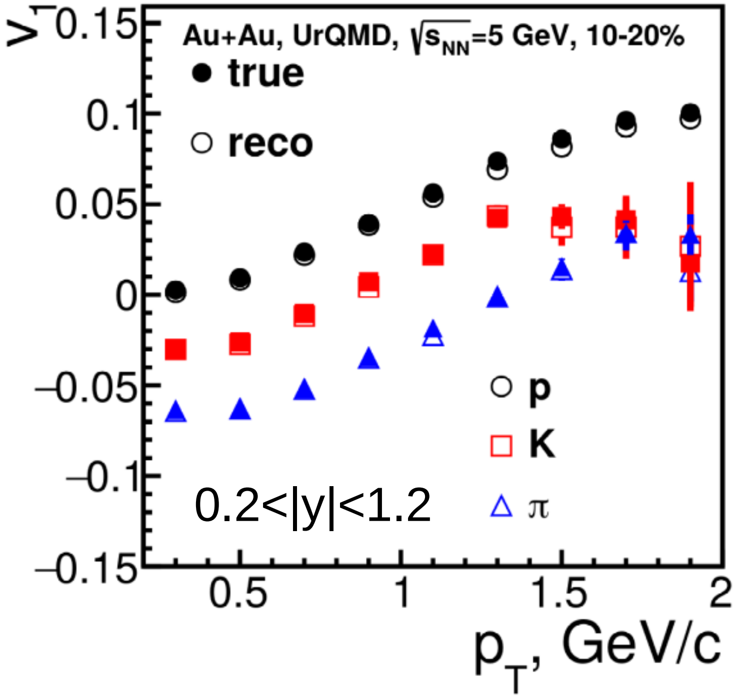
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

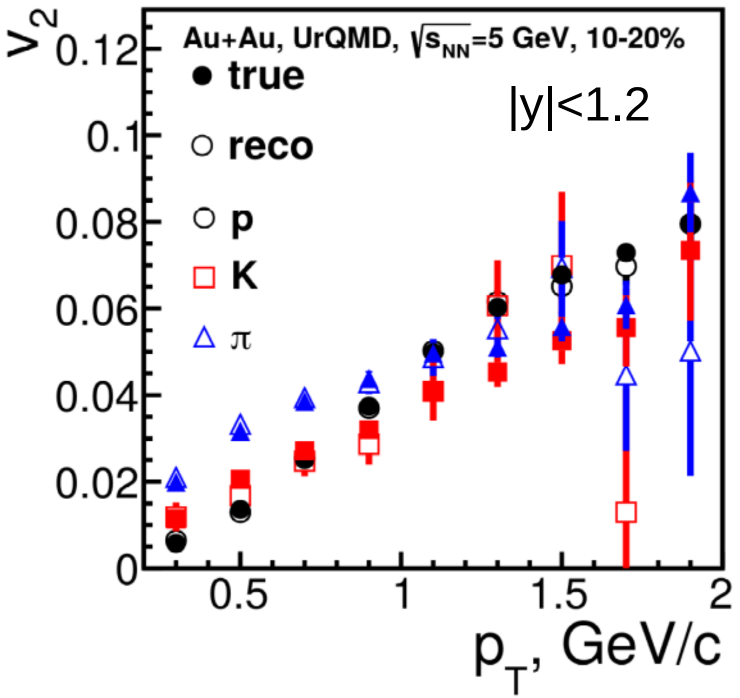




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

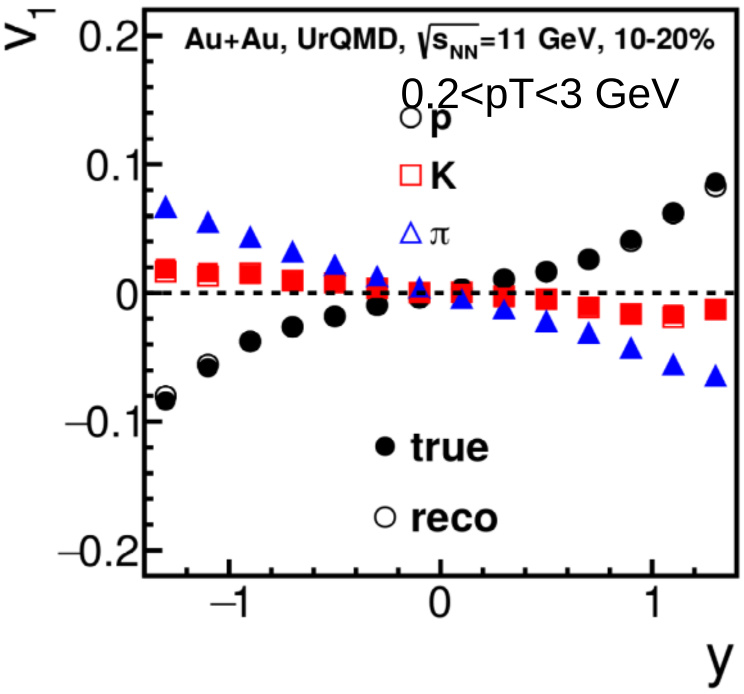
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV

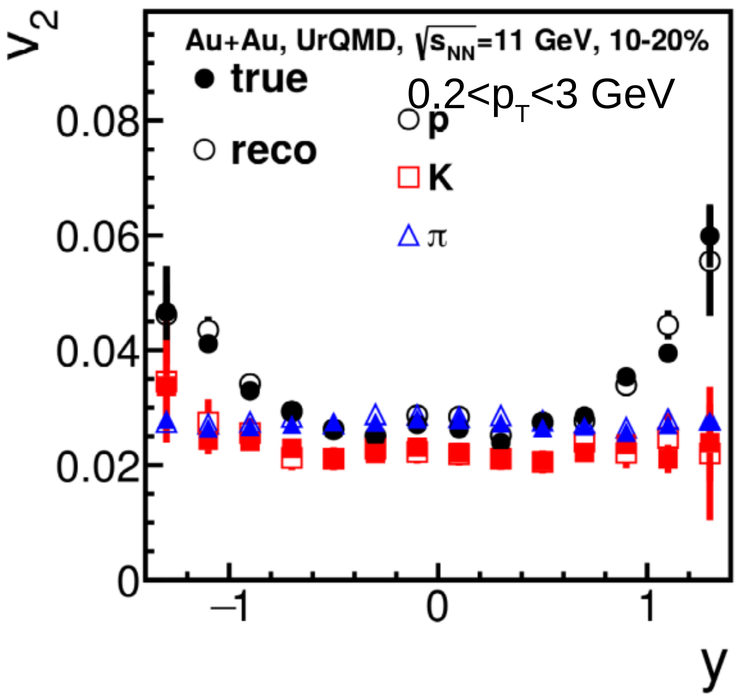




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

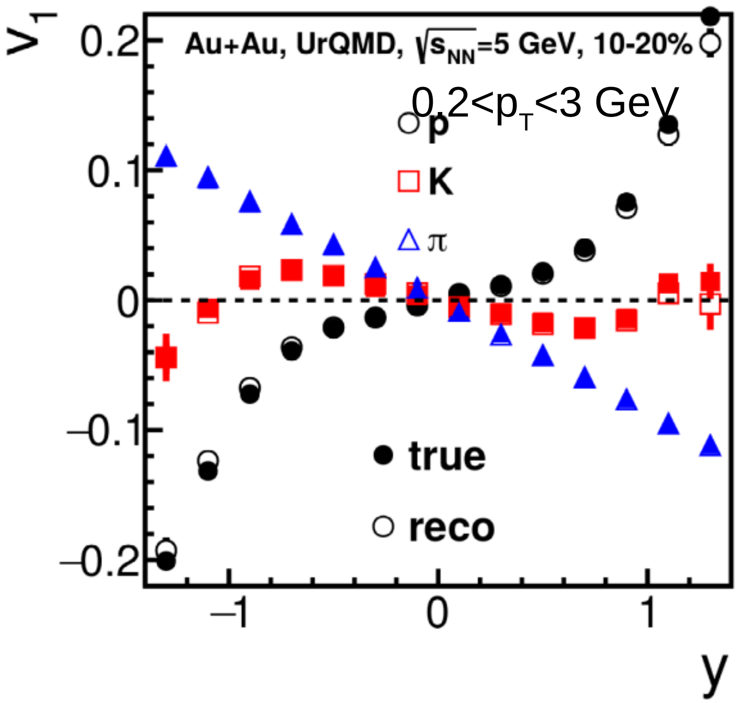
$v_{1,2}$ (y), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

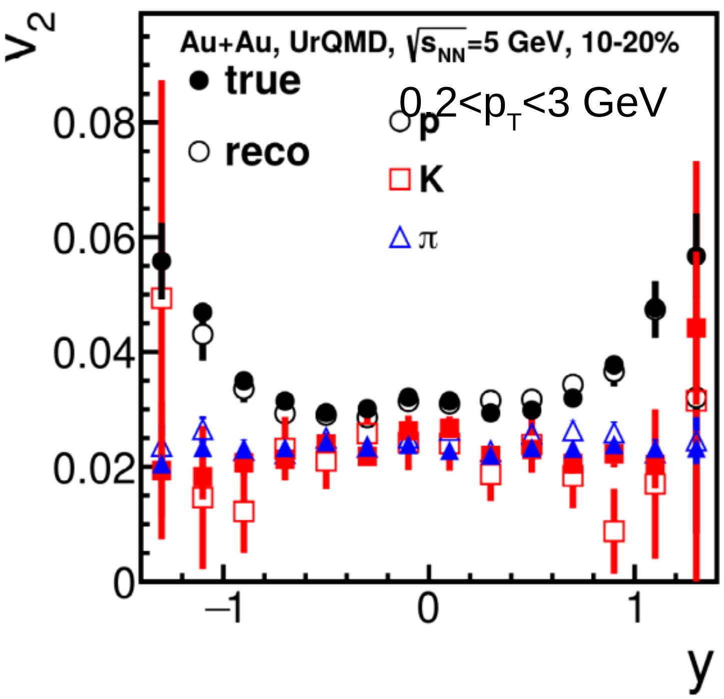




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

$v_{1,2}$ (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