Flow performance studies with MPD (NICA)

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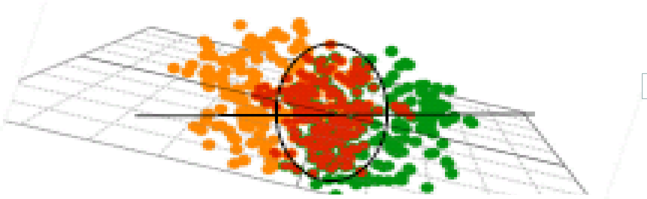
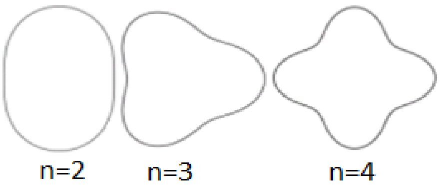
NC KI: D. Blau

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

Project supported by RFBR № 18-02-40086

Anisotropic Flow at RHIC-LHC

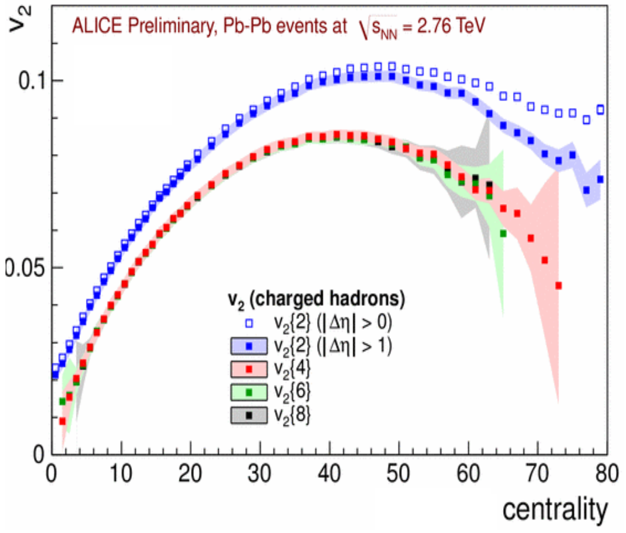




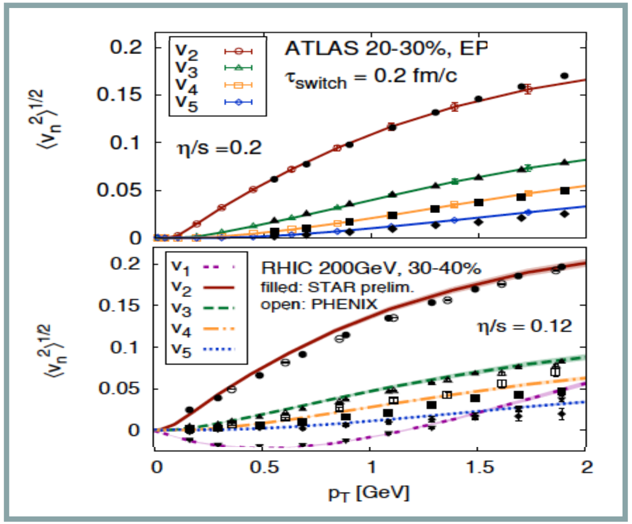
$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi \rangle + \langle r^n \sin n\phi \rangle}{\langle r^n \rangle}}$$

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

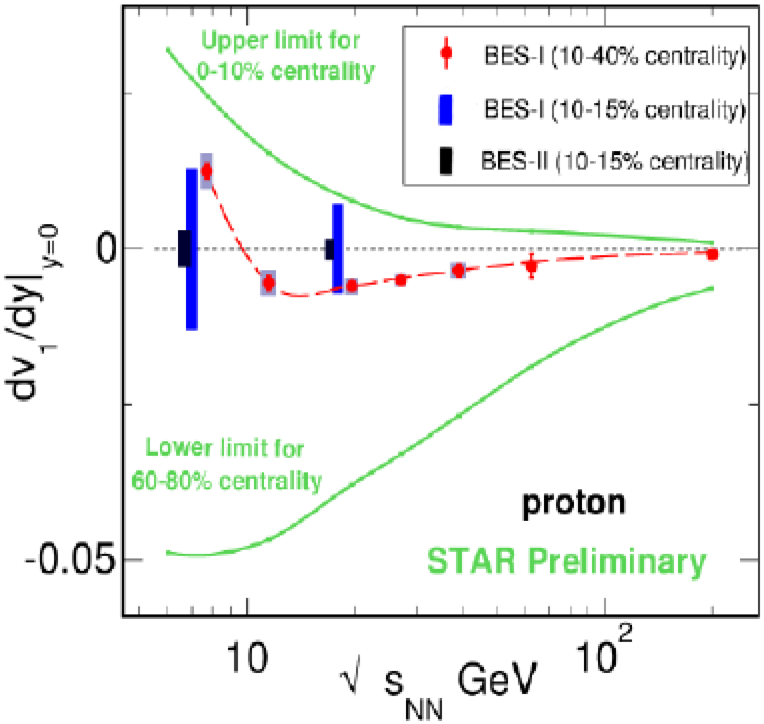
Initial eccentricity (and its attendant fluctuations) ε_n drive momentum anisotropy v_n with specific viscous modulation

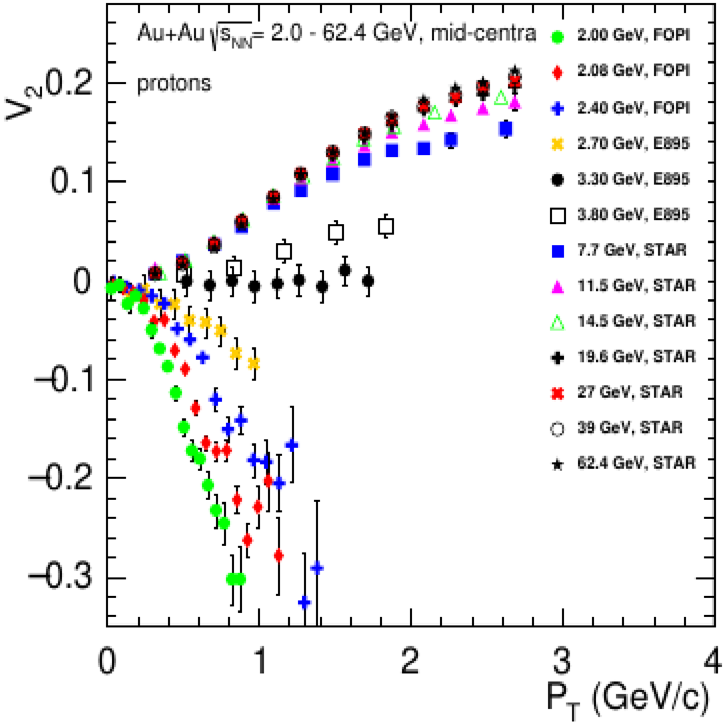


Different methods, non-flow, fluctuations



Anisotropic Flow at NICA energies





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

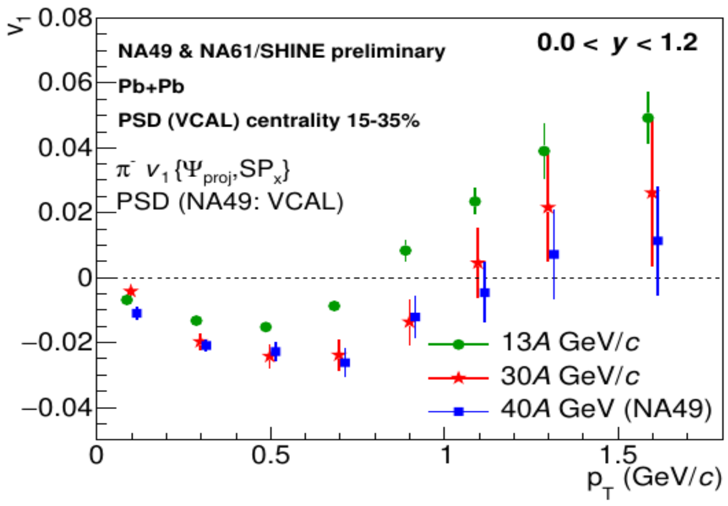
(2) NA61/NA49 Pb+Pb at 5.1, 7.6 and 8.9 GeV

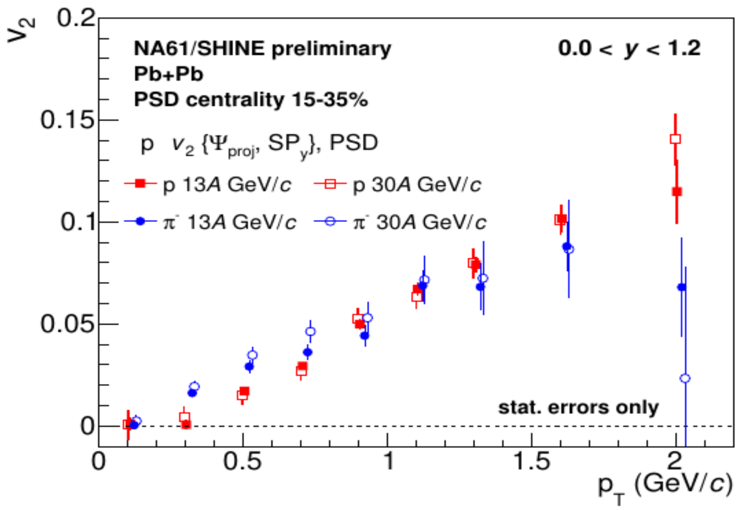
(3) STAR Collaboration Au+Au at 4.5, 7.7 and 11.5 GeV

Anisotropic flow at NICA energies   Models:

(1) String/Hadronic Cascade Models: UrQMD, HSD, SMASH, JAM, DCM-QGSM

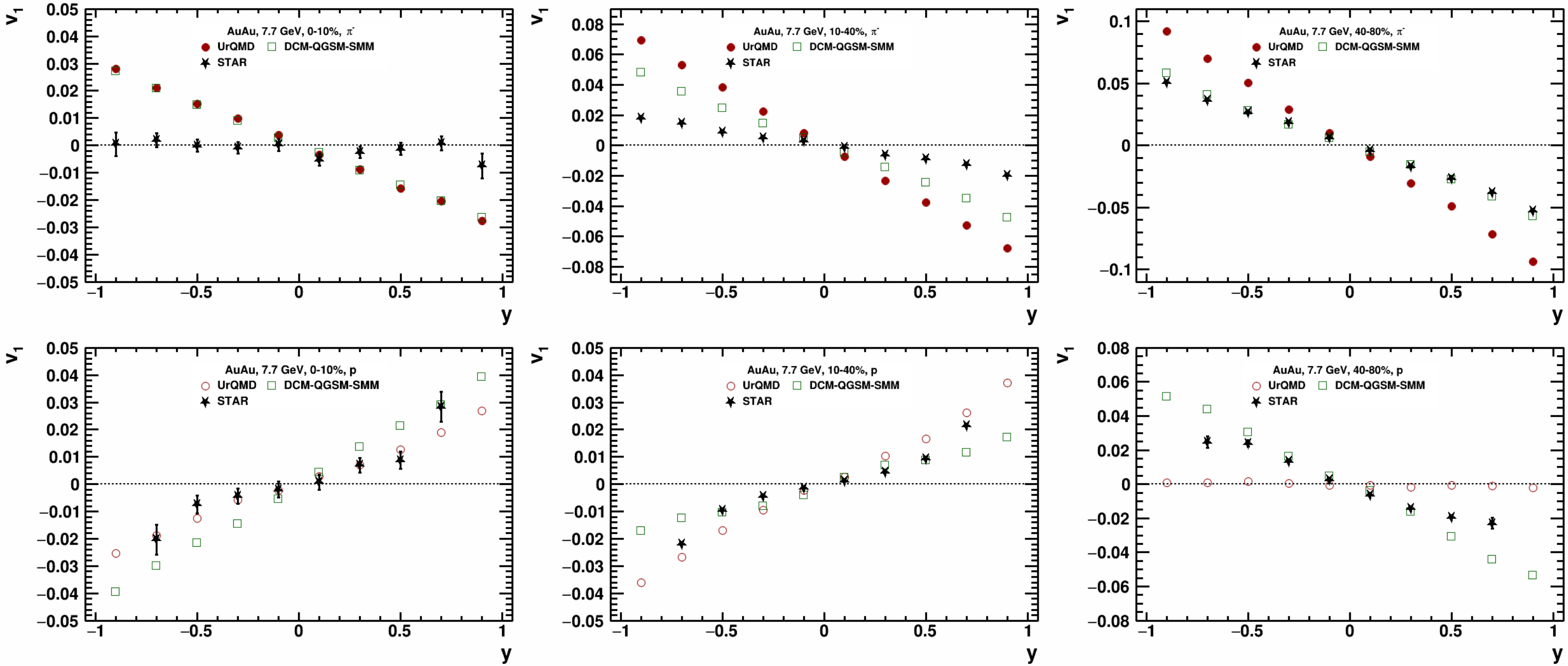
(2) Hybrid Models: viscous hydro+cascade (vHLLE+UrQMD и MUSIC+UrQMD) и parton/string models (AMPT, PHSD и PHQMD)





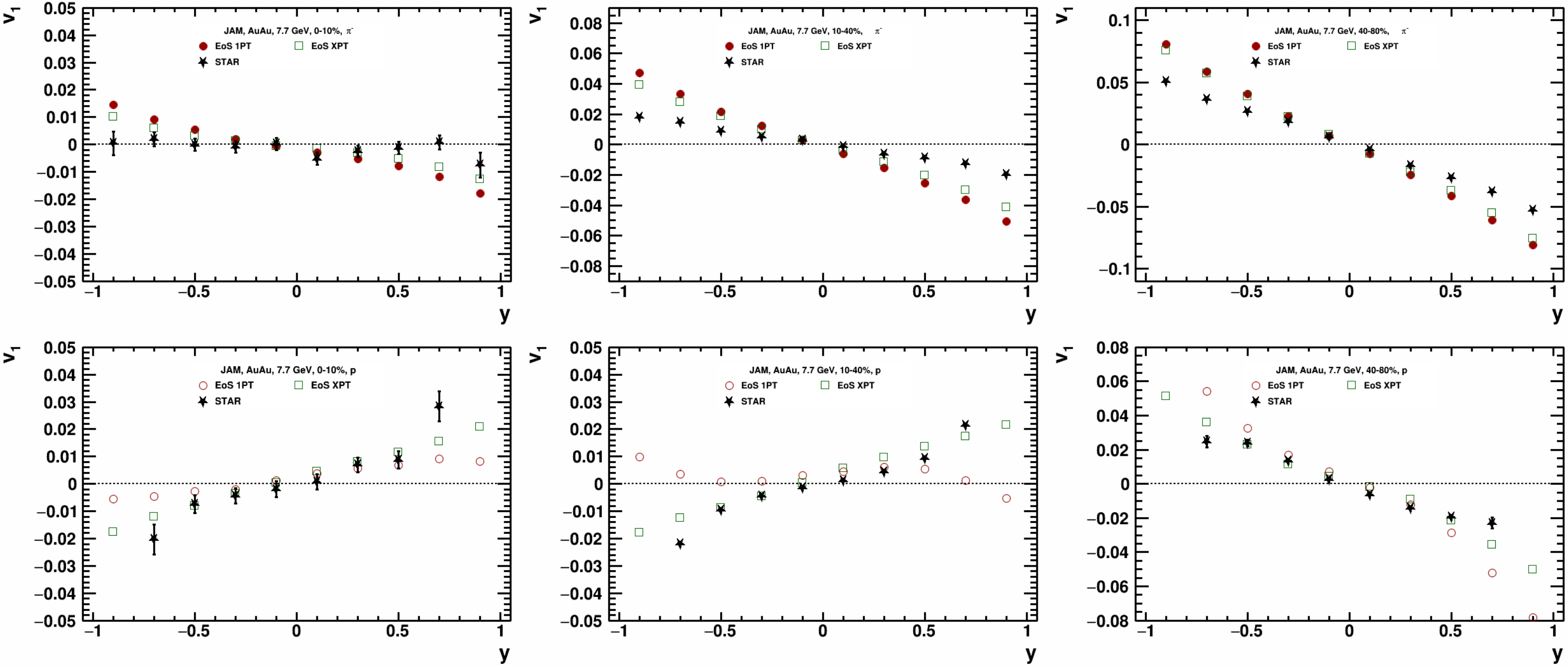
NA61/SHINE: Golosov. O , Kashirin E, Selyuzhenkov I. (WPCF 2019)

Directed flow: Models vs Data comparison



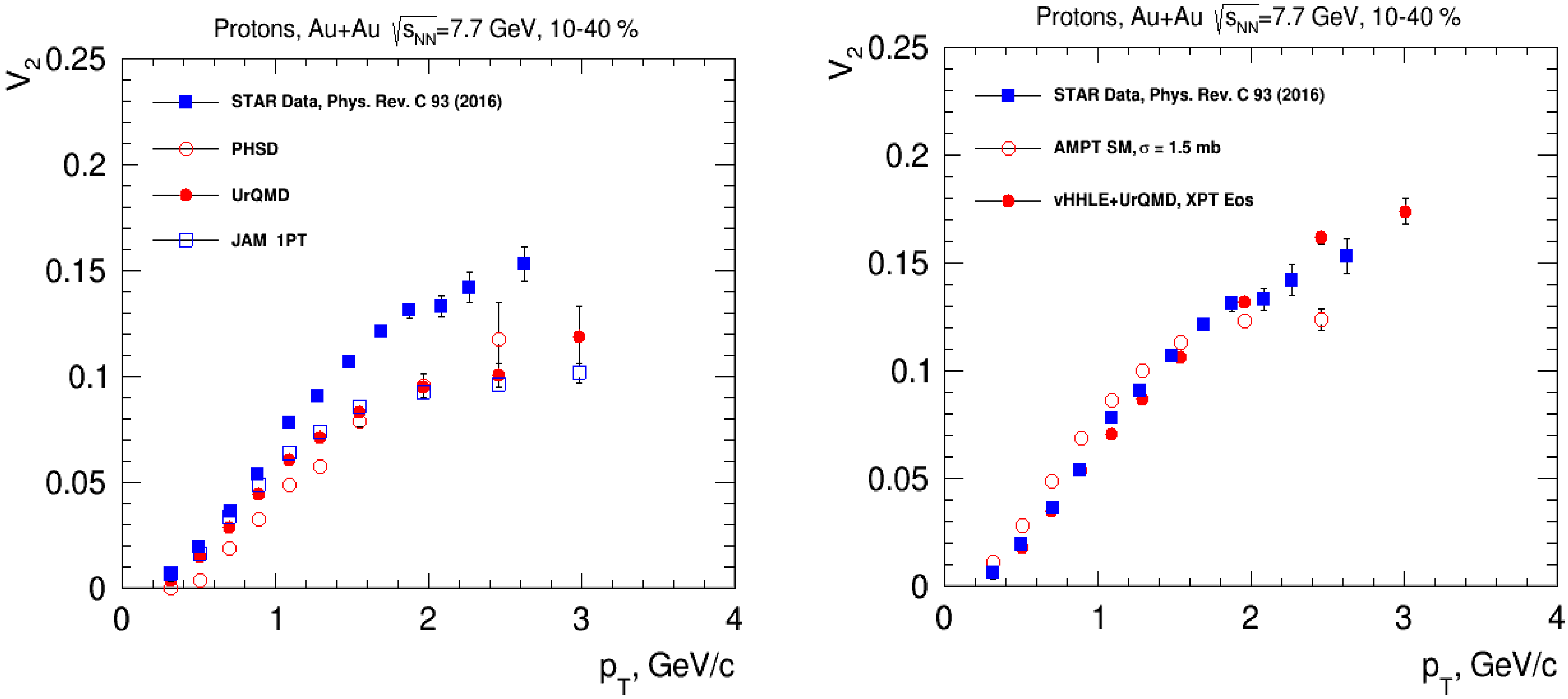
Models: DCM-QGSM-SMM and UrQMD vs STAR published data for Au+Au at $\sqrt{s_{NN}}$= 7.7 GeV (Phys. Rev. Lett. 112, no. 16, 162301 (2014))

Directed flow: Models vs Data comparison



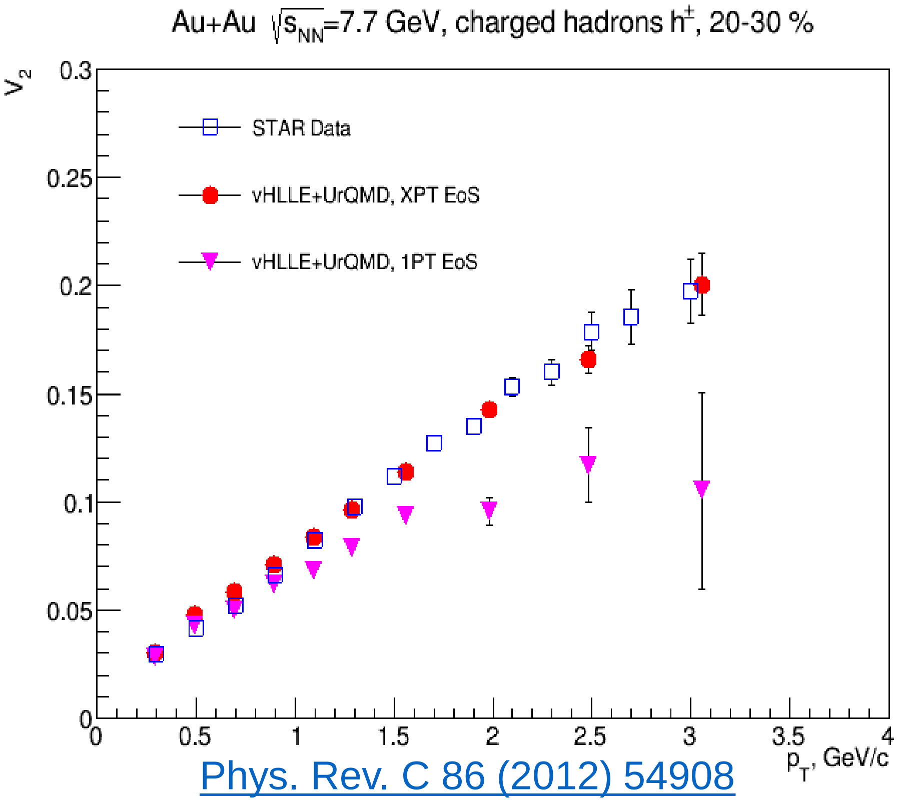
Models JAM (1PT vs XPT EOS) vs STAR published data for Au+Au at $\sqrt{s_{NN}}$= 7.7 GeV (Phys. Rev. Lett. 112, no. 16, 162301 (2014))

Elliptic flow: Models vs Data comparison

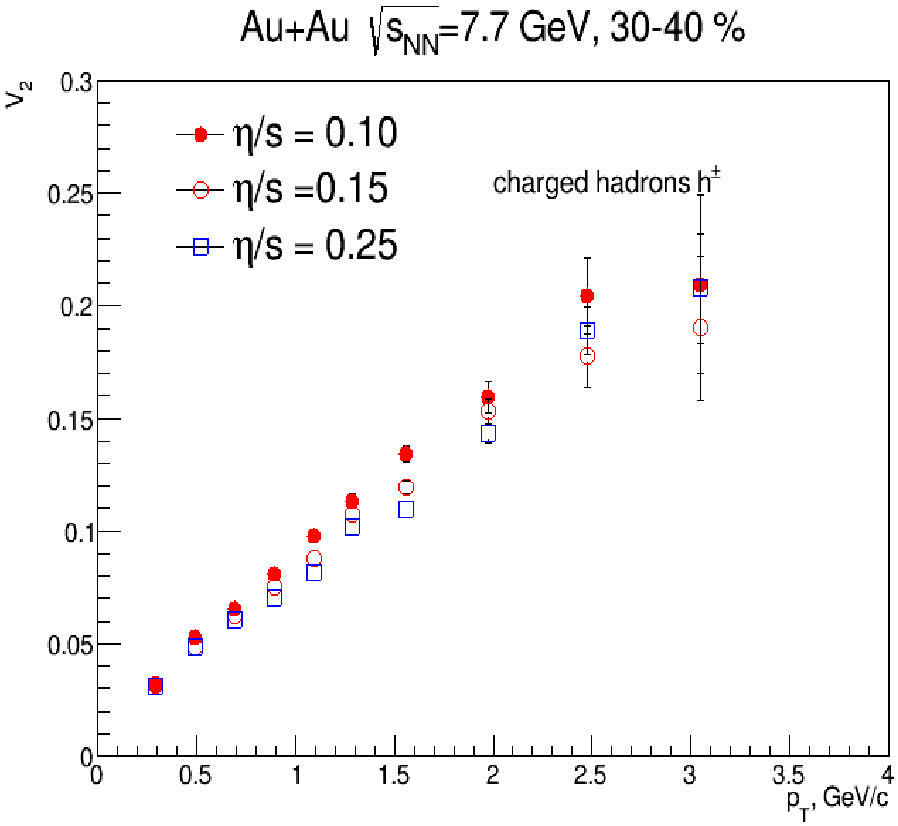


Pure String/Hadronic Cascade models give smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV

Differential elliptic flow: 3D hydro vHLLE + UrQMD



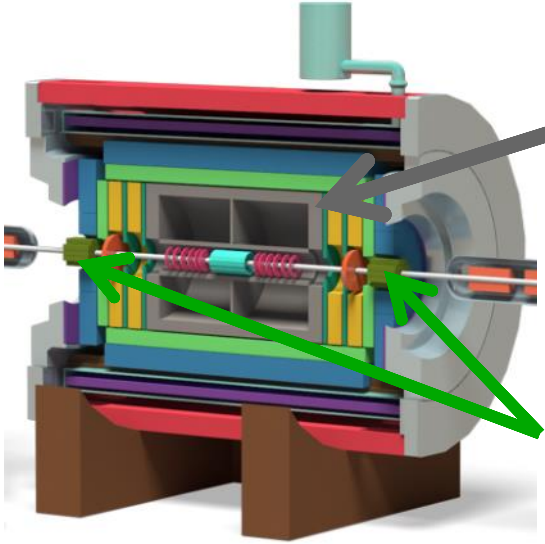
Phys. Rev. C 86 (2012) 54908



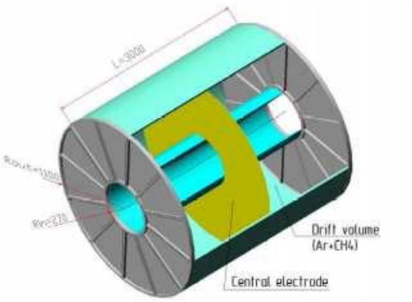
3D hydro model vHLLE + UrQMD shows sensitivity of v_2 to the EoS (XPT EoS vs 1PT EoS) and specific shear viscosity (η/s)

Flow performance study at MPD (NICA)

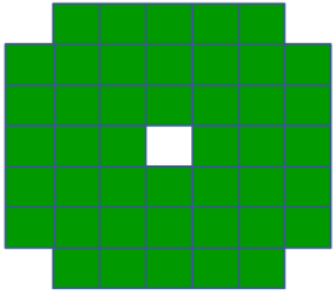
Multi Purpose Detector (MPD)



Time projection chamber (TPC)



Forward Hadron Calorimeter (FHCal)



EP plane

FHCal ($2<|\eta|<5$) or TPC ($|\eta|<1.5$)

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

$-5<\eta<-2$

FHCal

$-1.5<\eta<1.5$

TPC

$0.2<p_T<3$ GeV/c

$2<\eta<5$

FHCal

Setup, event and track selection

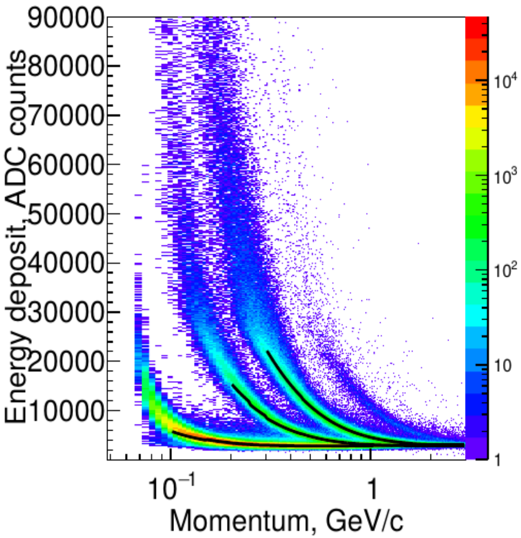
UrQMD → GEANT4 → Reconstruction → Flow analysis

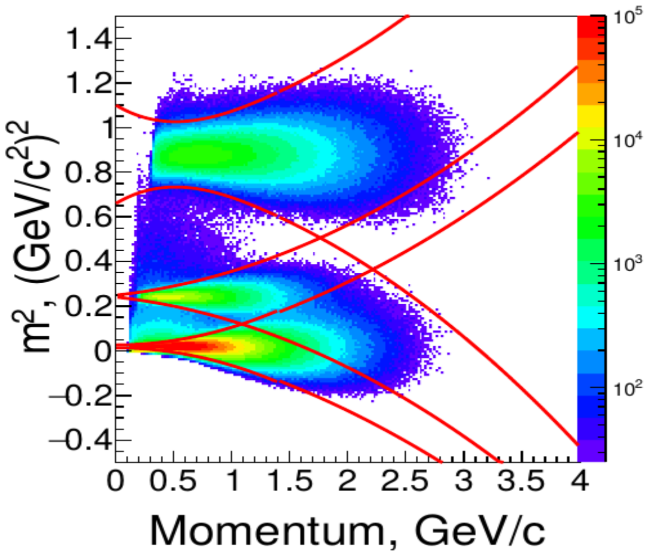
- Au+Au, N_{events} = 8 M events *at* $\sqrt{s_{NN}}$ = 4.5, 7.7 and 11 GeV
- Bi+Bi, N_{events} = 8 M events *at* $\sqrt{s_{NN}}$ = 7.7 GeV

- TPC
- FHCal
- TOF
- …

Event classification:
- Track multiplicity
- FHCal energy

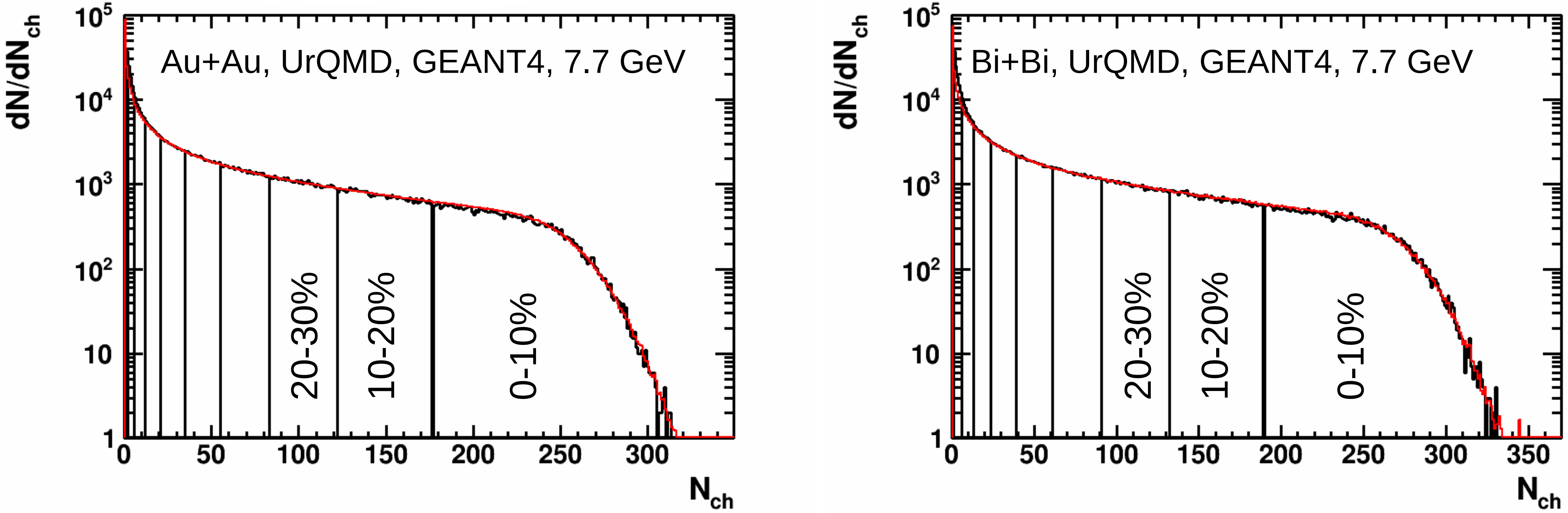
Track selection:
- Primary tracks (2σ DCA cut)
- $N_{TPC\ hits}$ > 32
- p_T>0.2 GeV/c
- |η| < 1.5
- PID based on TPC+TOF (MpdPid)





MPDRoot, December 2019

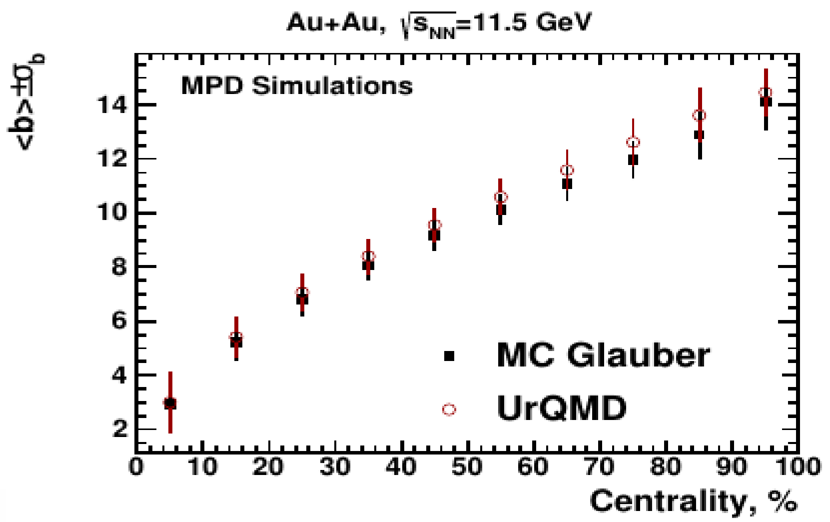
MC Glauber Centrality Framework for MPD

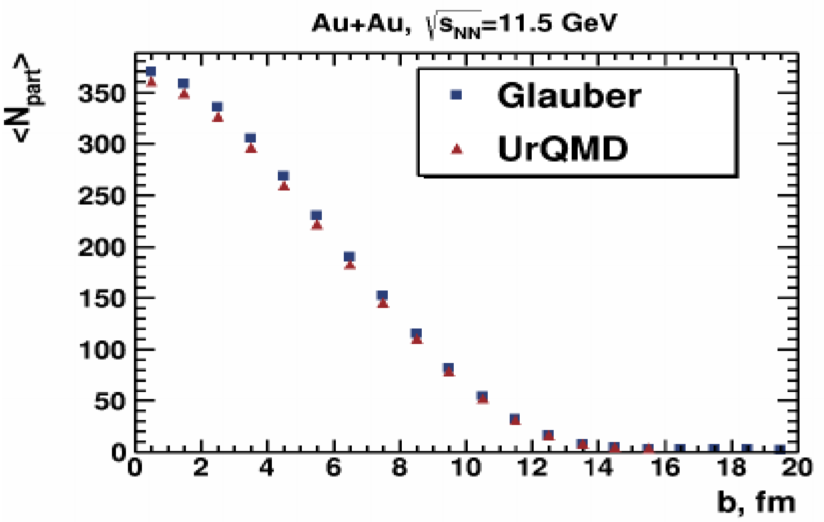


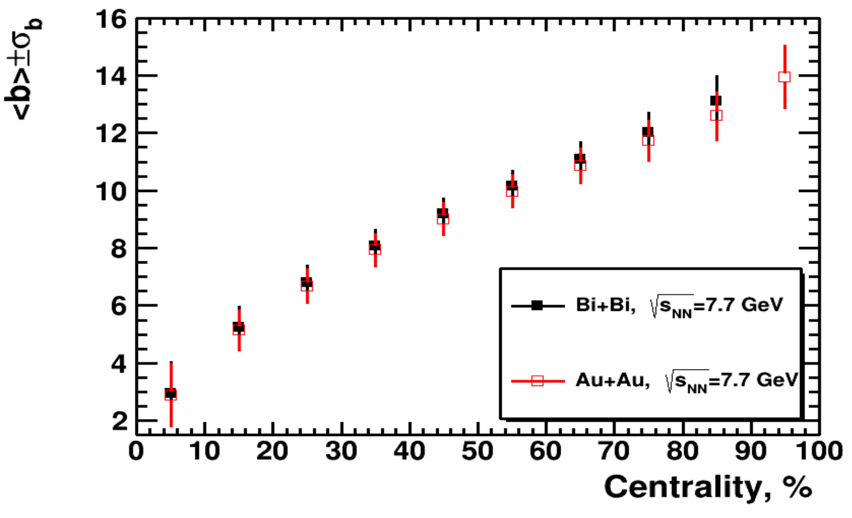
This centrality procedure was used in CBM, NA49, and NA61/SHINE: Acta Phys.Polon.Supp. 10 (2017) 919
Implemantation in MPD: https://github.com/IlyaSegal/NICA

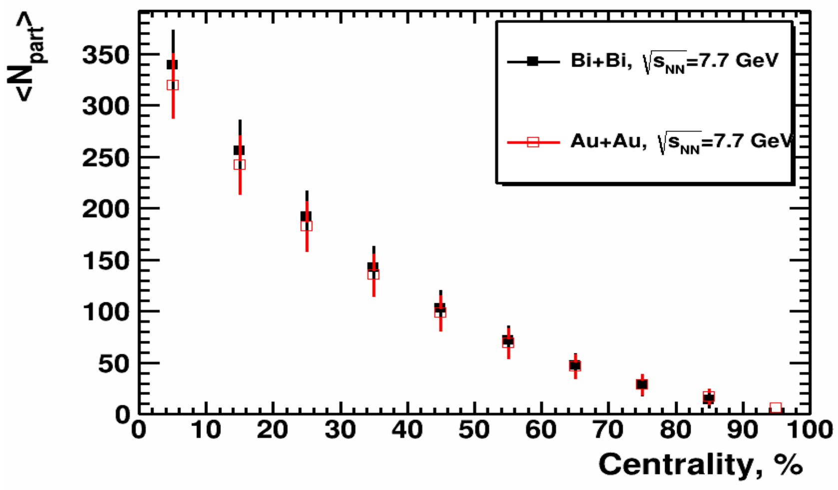
Parfenov. P , Selyuzhenkov I., Segal. I

MC Glauber Centrality Framework

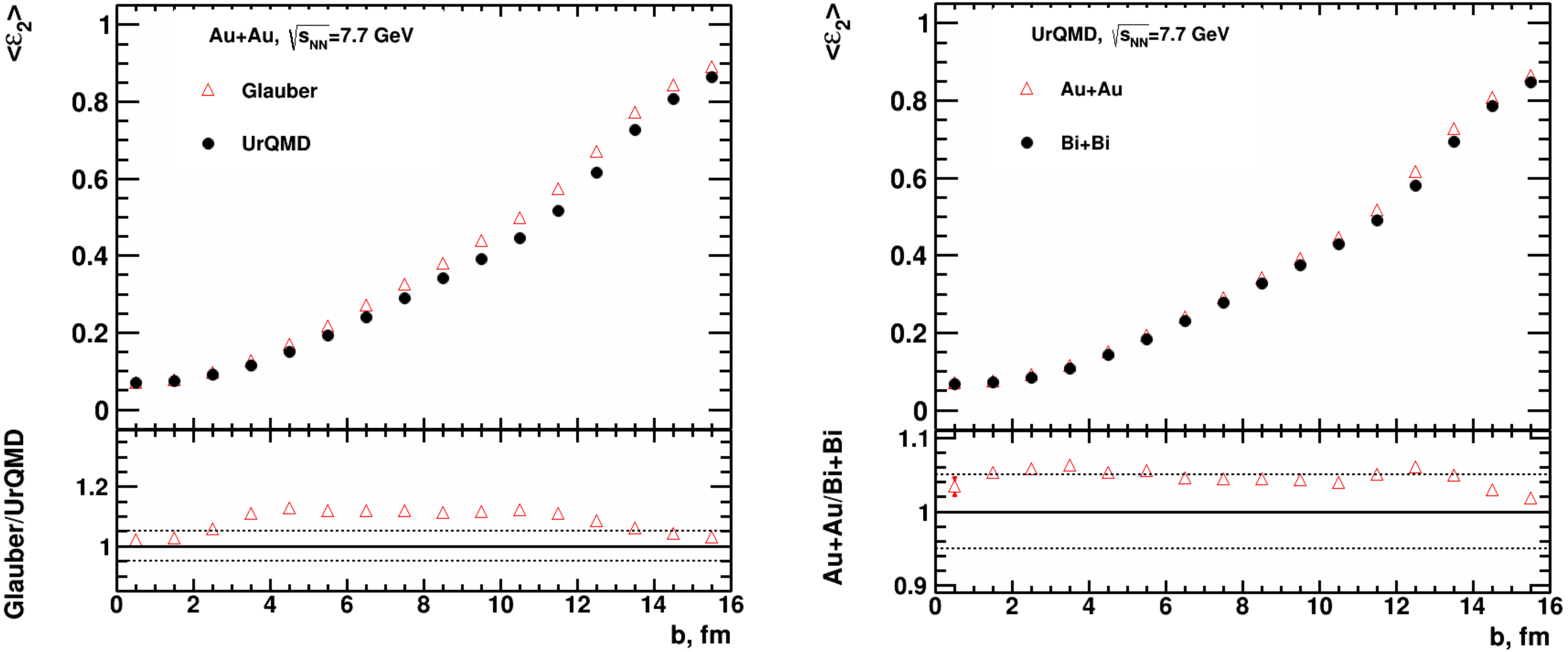








Eccentricity: Bi+Bi vs Au+Au



Expected small difference between MC Glauber eccentricities for Au+Au and Bi+Bi

Event plane method implementation in MPD (NICA)

Both left and right FHCal parts were used:

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

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

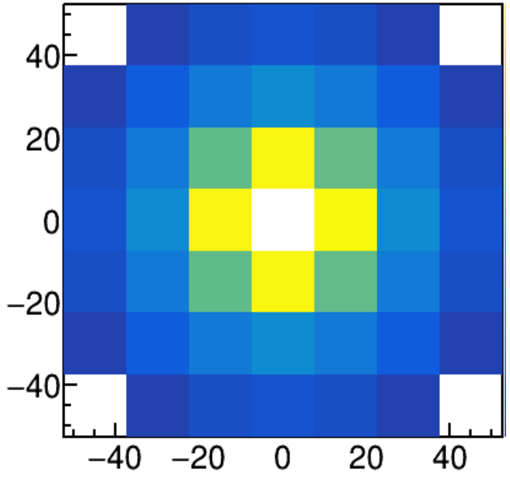
$$m = 1 \text{ was used}$$

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

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

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

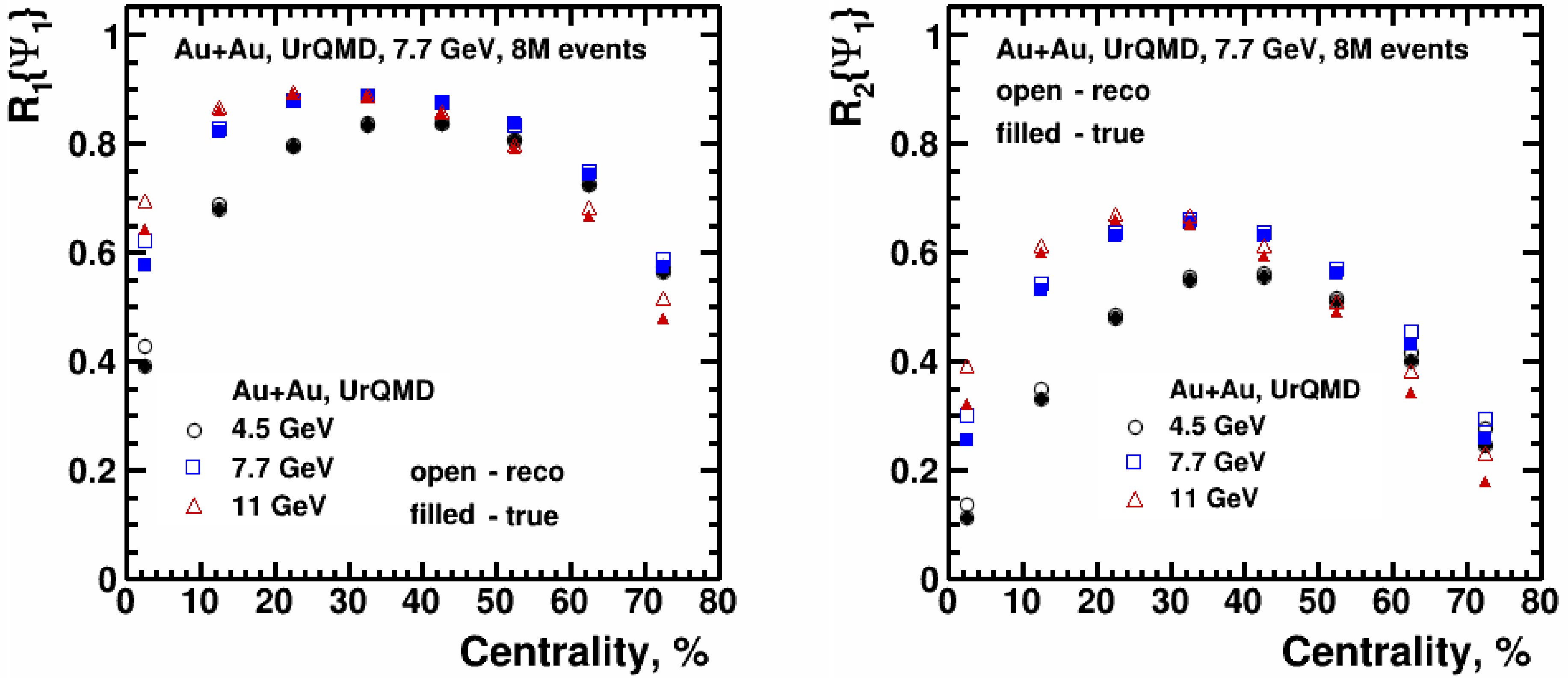
- E_i is the energy deposition in *i-th* FHCal module
  φ_i is its azimuthal angle.
- For *m=1* weights had different signs for backward and forward rapidity.
- Δη-gap>0.5 between TPC and FHCal suppresses non-flow contribution



Energy distribution in FHCal

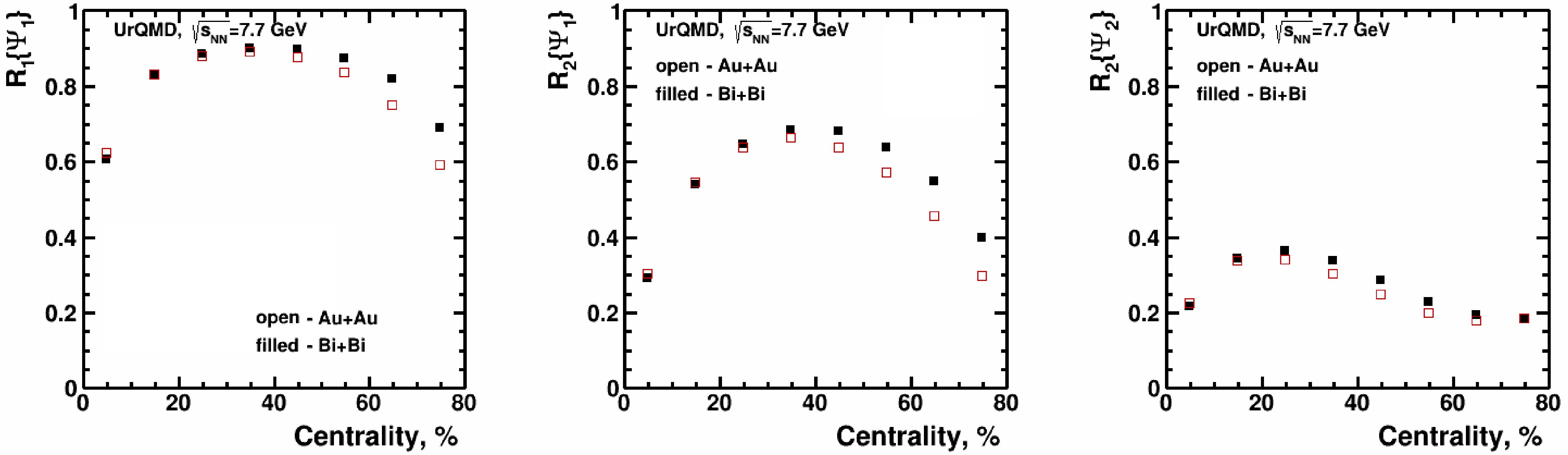
https://git.jinr.ru/nica/mpdroot/tree/dev/macro/physical_analysis/Flow

EP Resolution: energy dependence



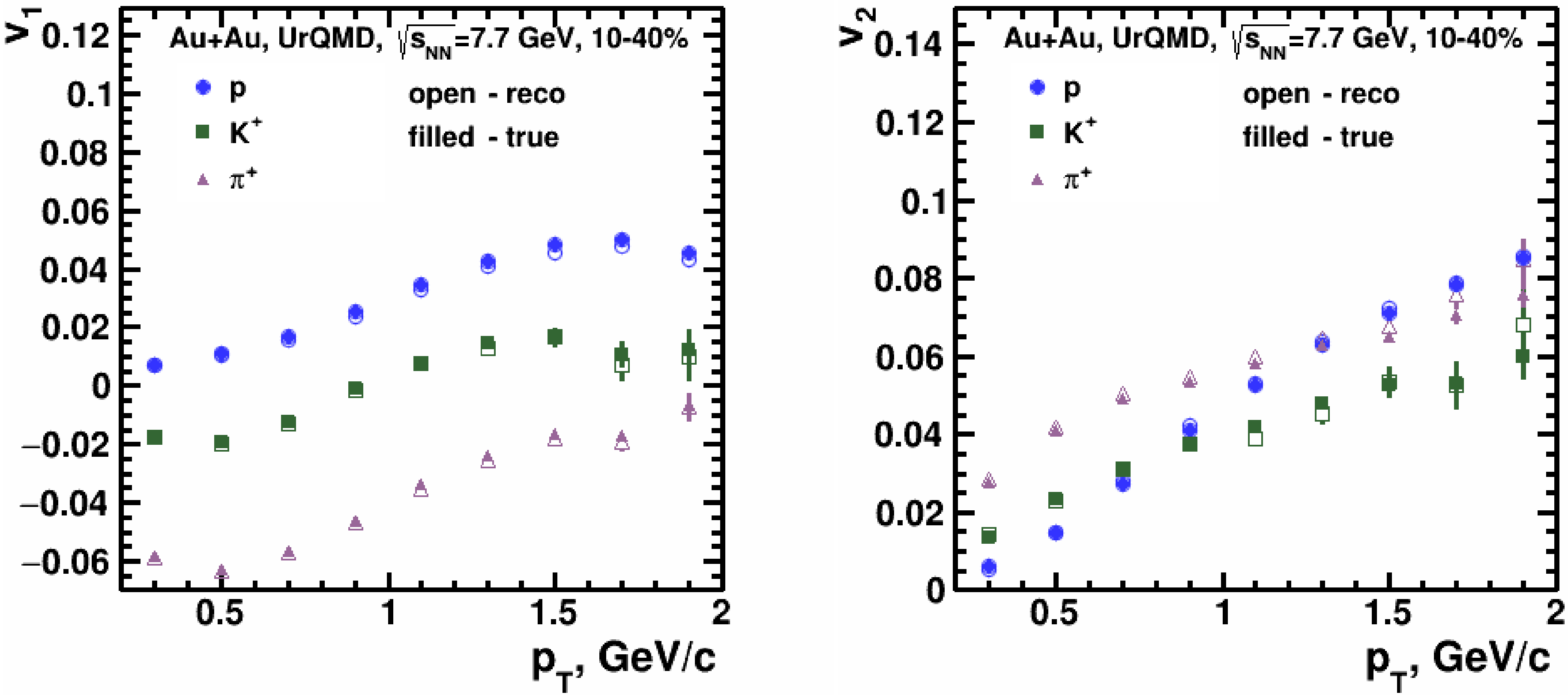
Good performance in the centrality range 0-80% for NICA collision energy range

EP Resolution: Bi+Bi vs Au+Au



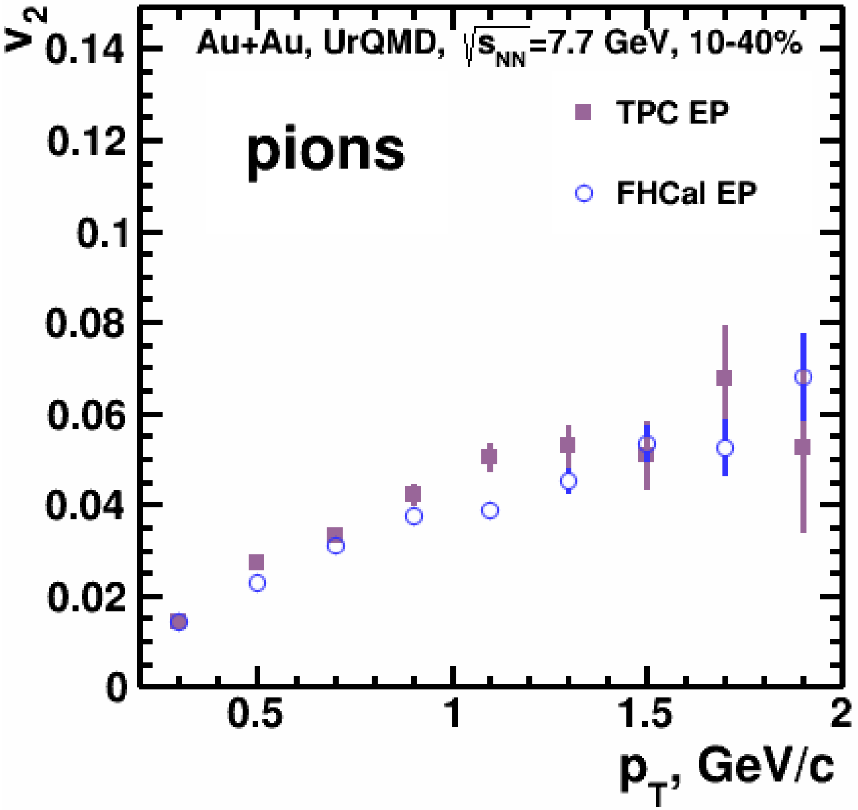
Expected small difference between EP resolutions for Au+Au and Bi+Bi

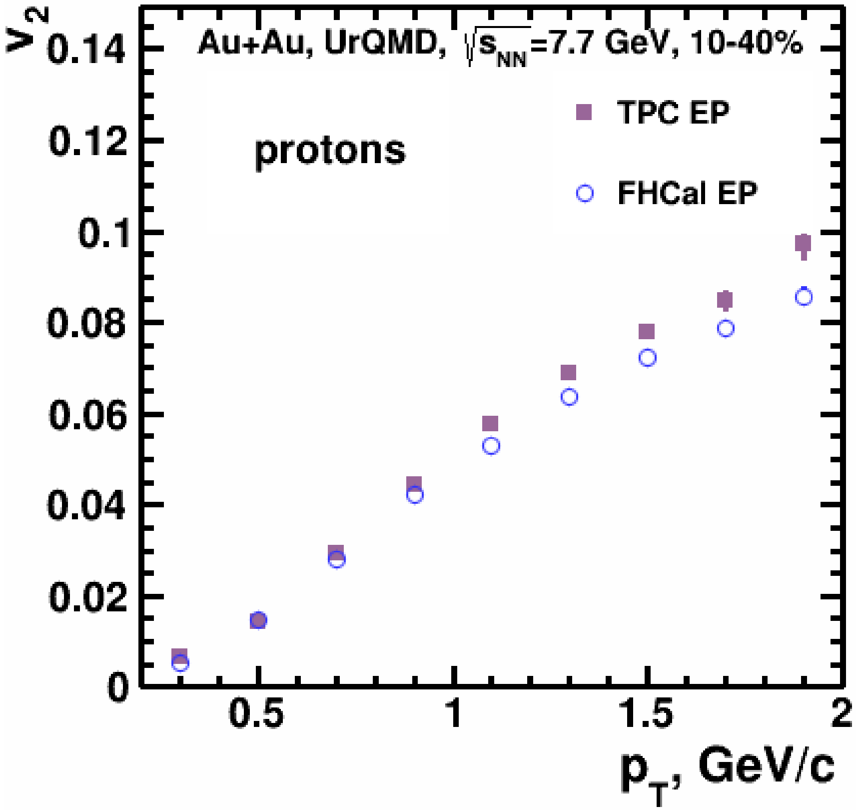
p_T-dependence of v_1 and v_2 of reconstructed signal



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

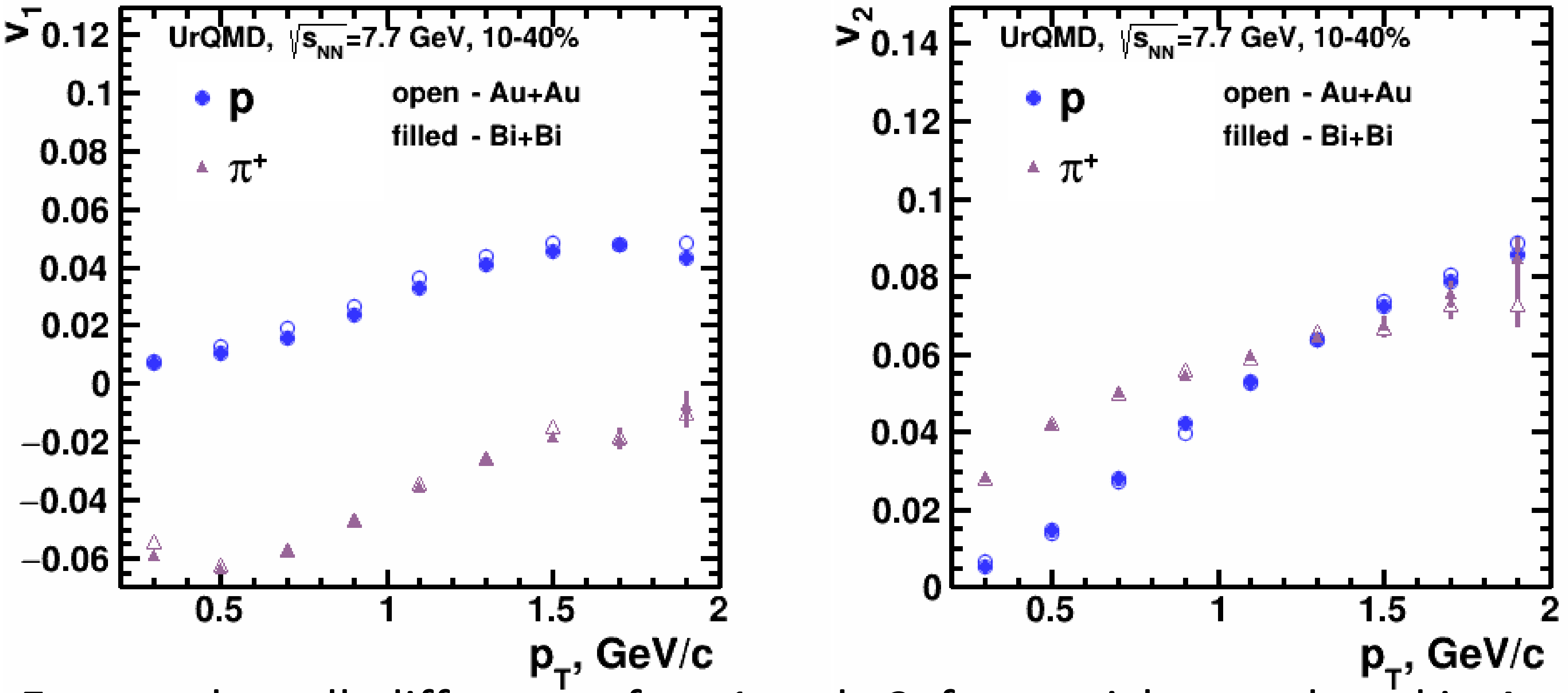
$v_2(p_T)$: FHCal EP vs TPC EP





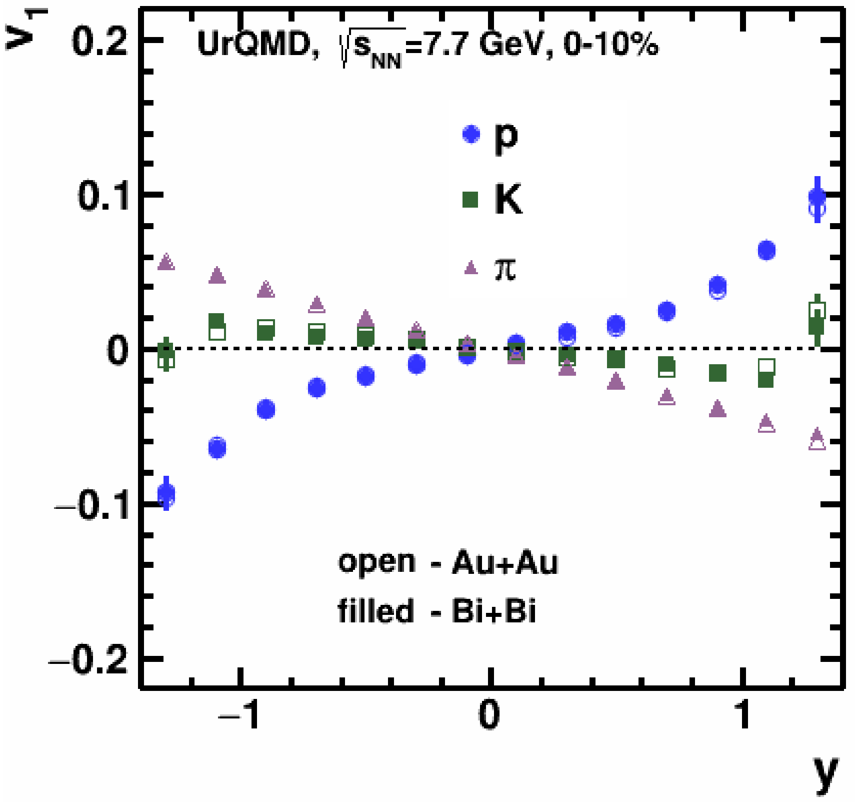
Expected small difference between v2 measured with respect TPC (EP2 plane) and FHCal (EP1 plane)

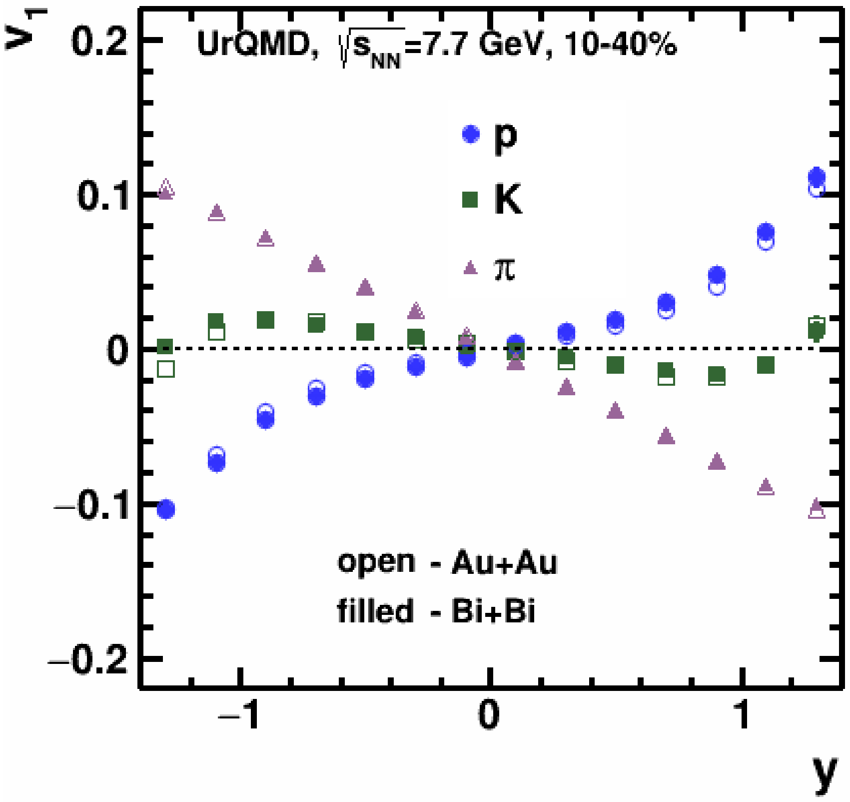
$v_n(p_T)$: Bi+Bi vs Au+Au



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 v1 (y) for particles produced in Au+Au and Bi+Bi collisions.

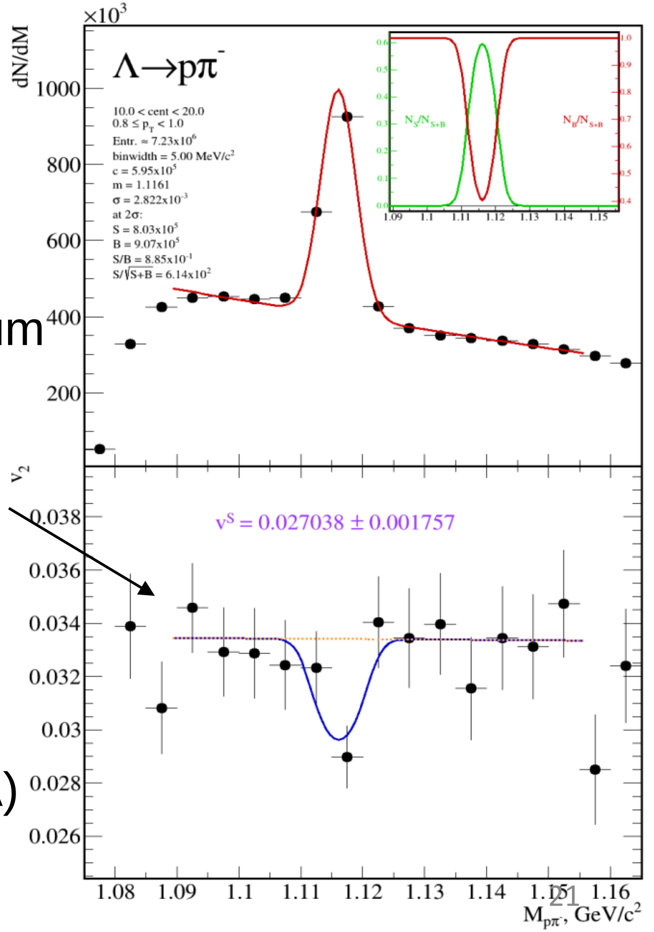
Anisotropic Flow of V0 Particles (Nikolay Geraksiev)

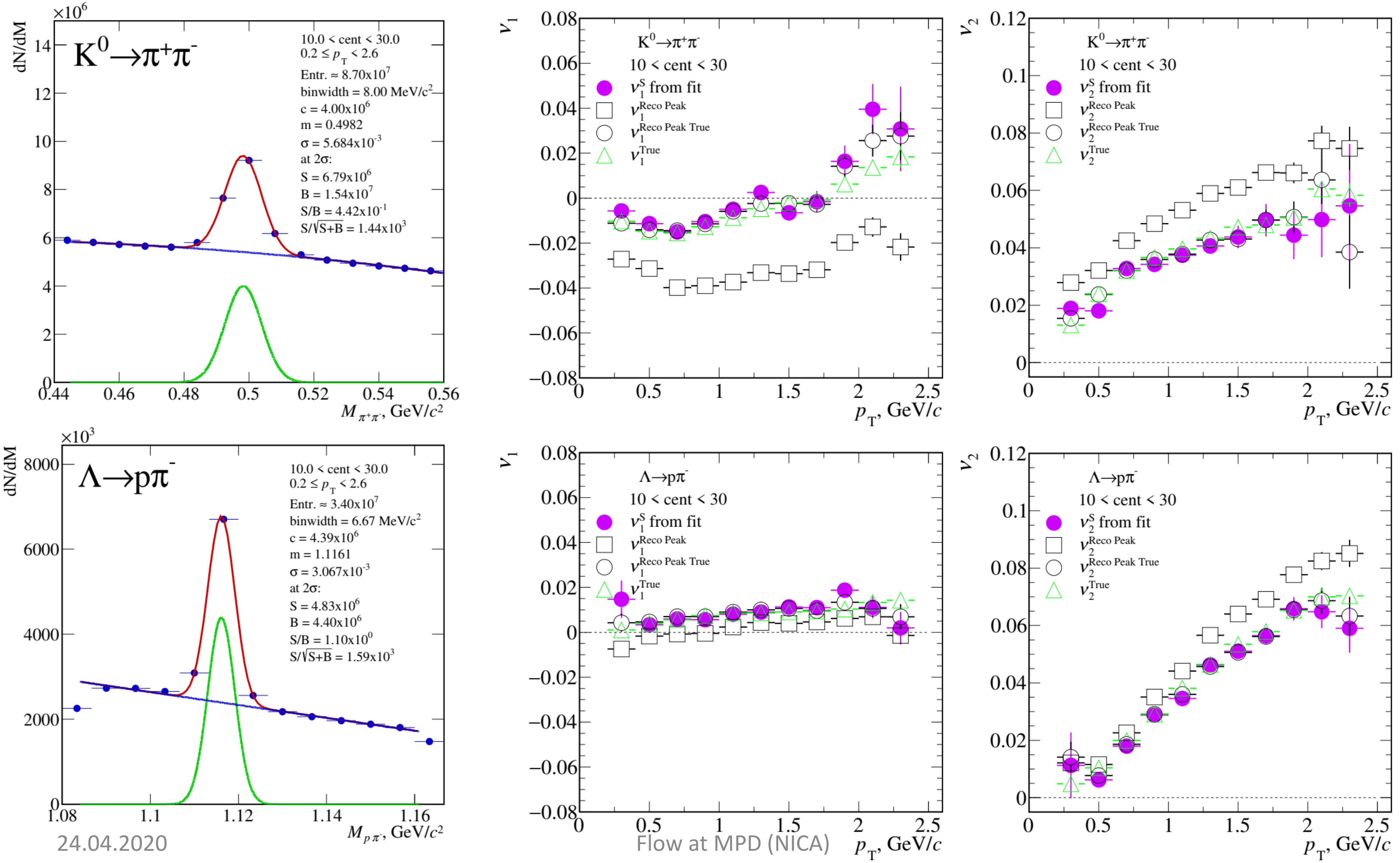
1. Plovdiv University "Paisii Hilendsrski", Bulgaria
2. VBLHEP JINR, Russia

- 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)





K0→π+π-
10.0 < cent < 30.0
0.2 ≤ pT < 2.6
Entr. ≈ 8.70x10^7
binwidth = 8.00 MeV/c^2
c = 4.00x10^6
m = 0.4982
σ = 5.684x10^-3
at 2σ:
S = 6.79x10^6
B = 1.54x10^7
S/B = 4.42x10^-1
S/√(S+B) = 1.44x10^3
dN/dM
×10^6
M π+π-, GeV/c^2
K0→π+π-
10 < cent < 30
v1S from fit
v1Reco Peak
v1Reco Peak True
v1True
v1
pT, GeV/c
v2S from fit
v2Reco Peak
v2Reco Peak True
v2True
v2
Λ→pπ-
10.0 < cent < 30.0
0.2 ≤ pT < 2.6
Entr. ≈ 3.40x10^7
binwidth = 6.67 MeV/c^2
c = 4.39x10^6
m = 1.1161
σ = 3.067x10^-3
at 2σ:
S = 4.83x10^6
B = 4.40x10^6
S/B = 1.10x10^0
S/√(S+B) = 1.59x10^3
×10^3
M pπ-, GeV/c^2

Summary

sotropic flow performance study in MPD (NICA):

l reconstruction chain was implemented:

mbined particle identification based on TPC and TOF

alistic hadronic simulation (GEANT4)

ent plane from FHCal and TPC

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

del/Data comparison:

re string/hadronic cascade models give smaller v_2 signal compared

STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV

$_T$) from 3D hydro model vHLLE + UrQMD and AMPT model are in a good agreement with STAR dat

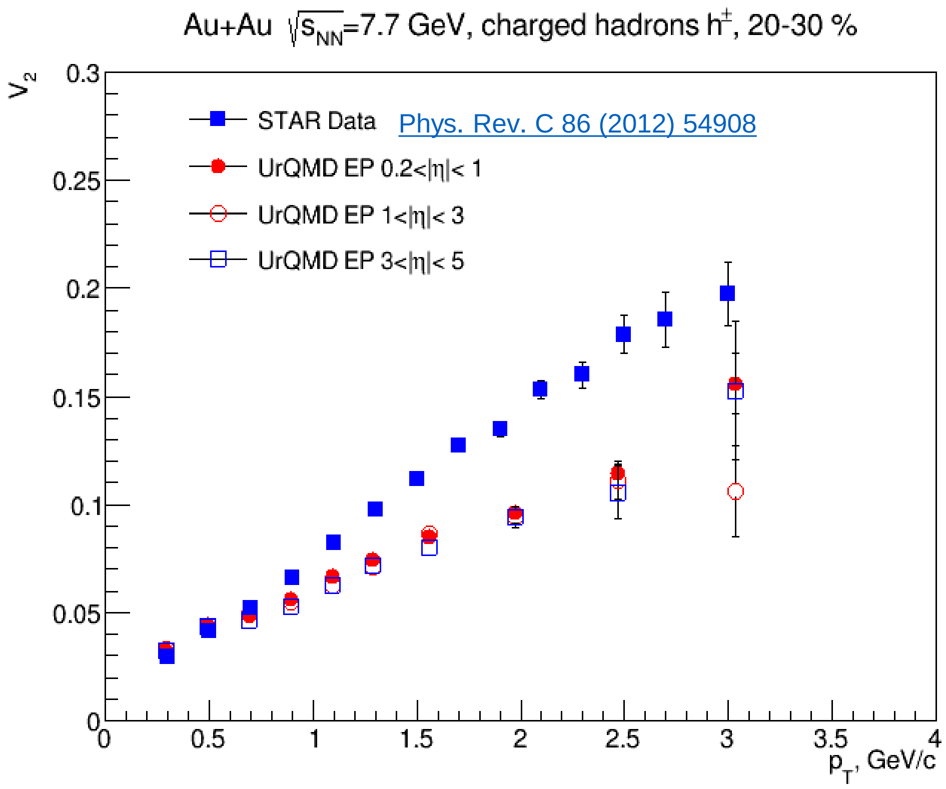
otic flow are sensitive to the EoS (1PT or XPT) and η/s

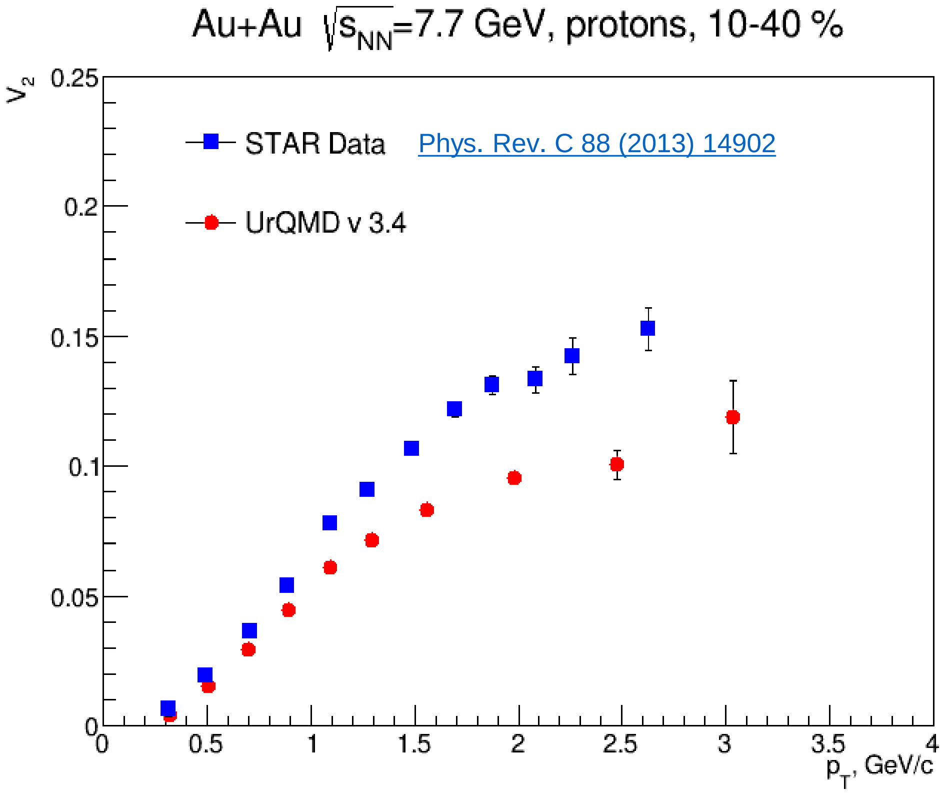
e situation with good model description worse for directed flow

Thank you for your attention!

Backup

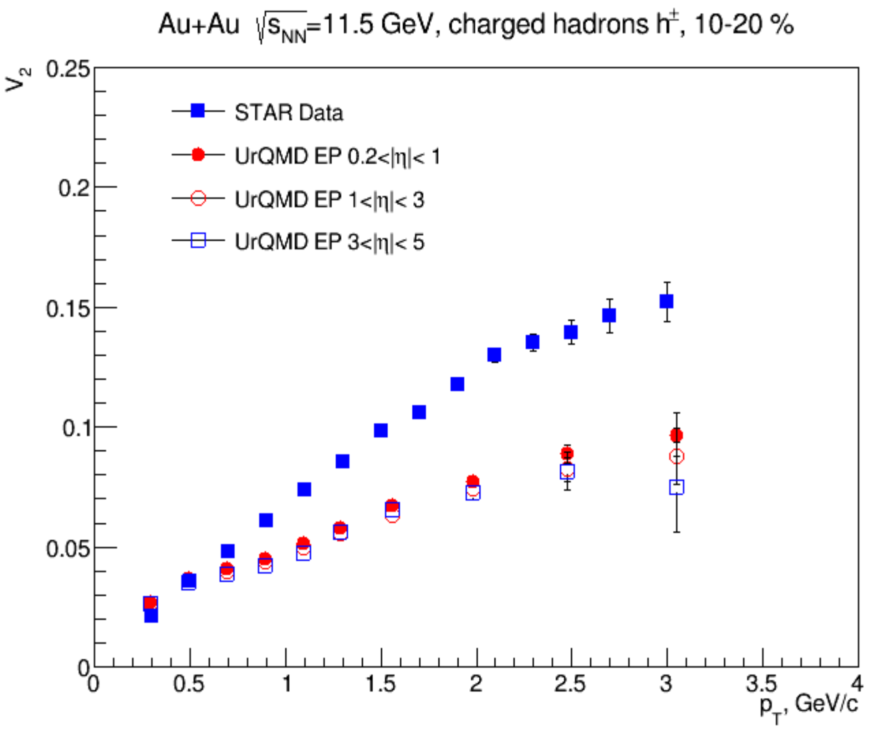
BES: differential elliptic flow: UrQMD

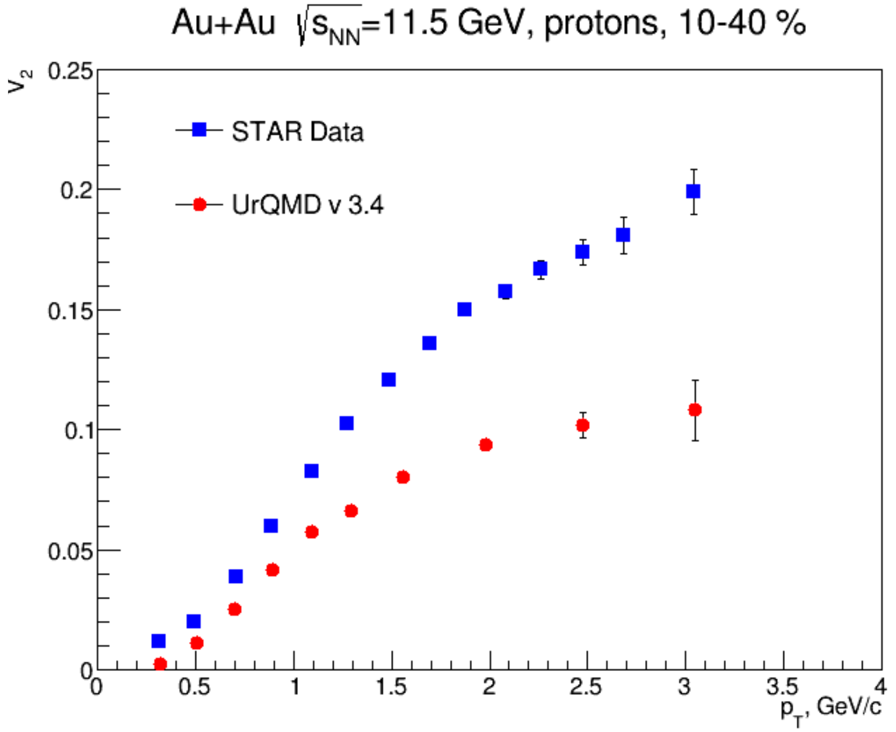




What about other “hadronic” models: SMASH, JAM, HSD? - Under investigation

BES: differential elliptic flow: UrQMD

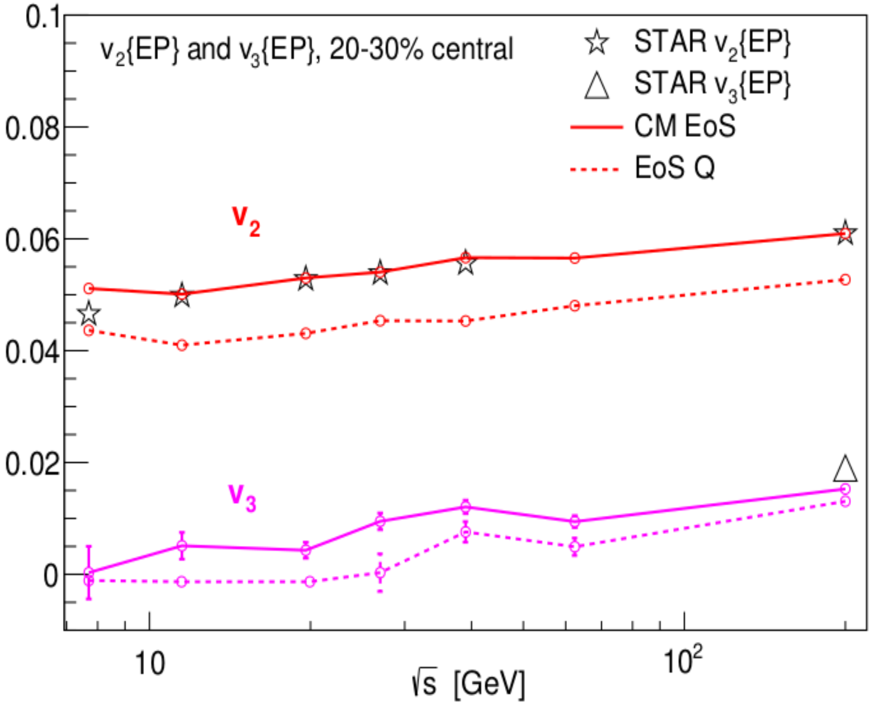


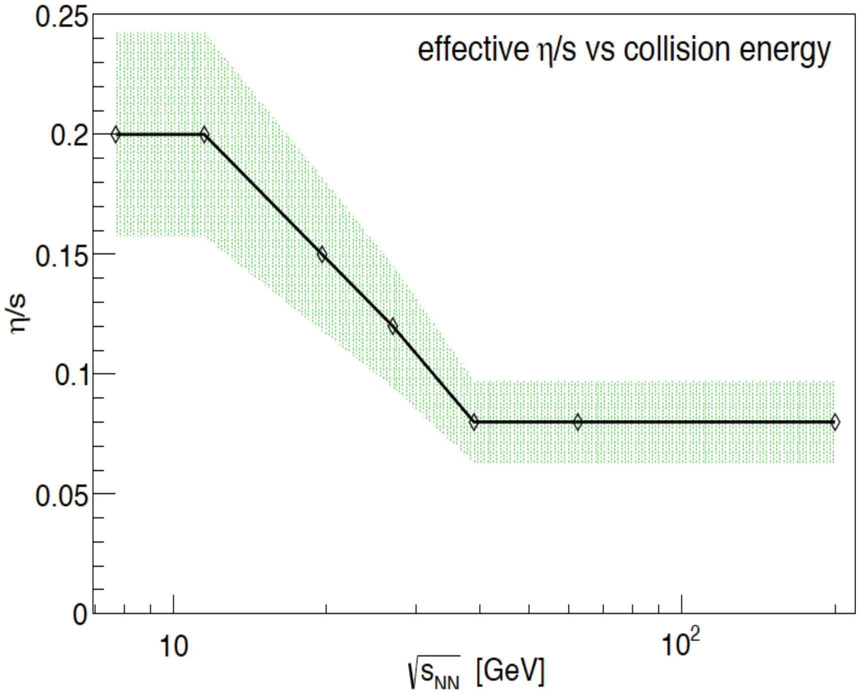


What about other "hadronic" models: SMASH, JAM, HSD? - Under investigation

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

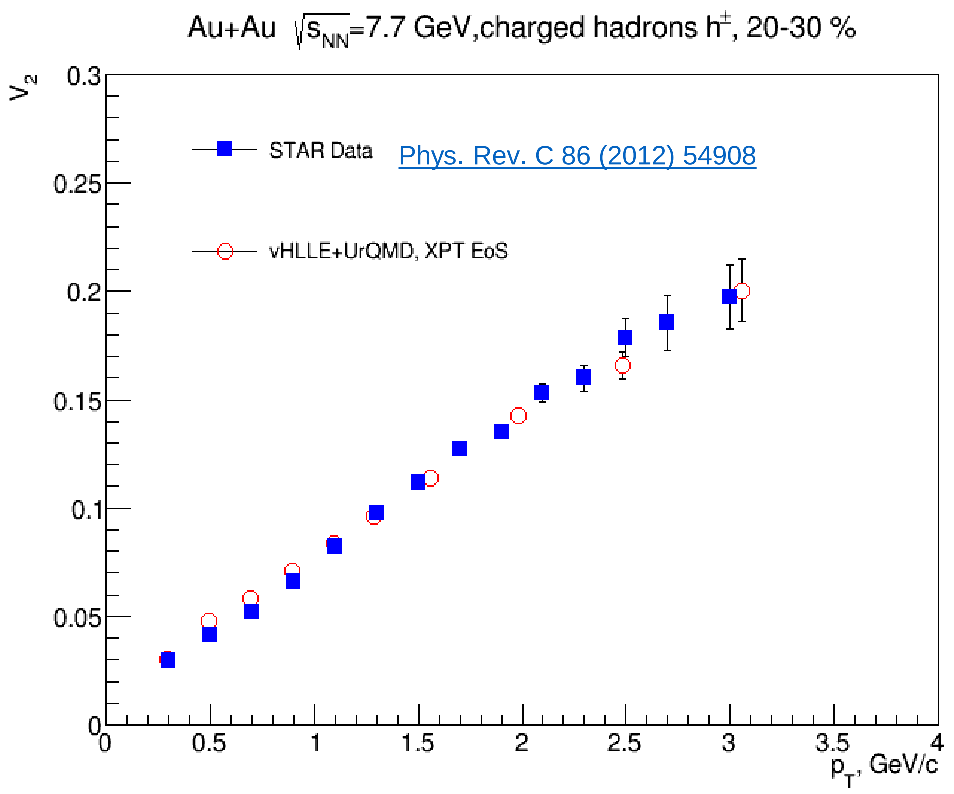


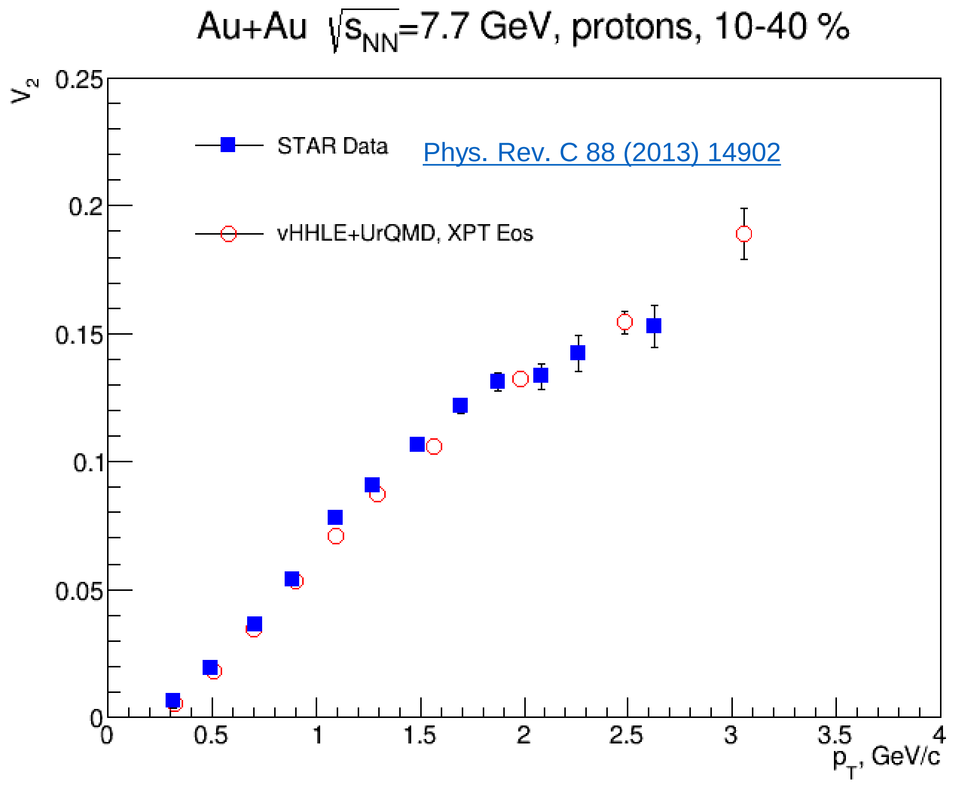


Hybrid model: UrQMD + 3D hydro model vHLLE + UrQMD

Shows good agreement with published STAR data for integrated $v_n(\sqrt{s_{NN}})$ from BES-I

Differential elliptic flow: 3D hydro vHLLE + UrQMD



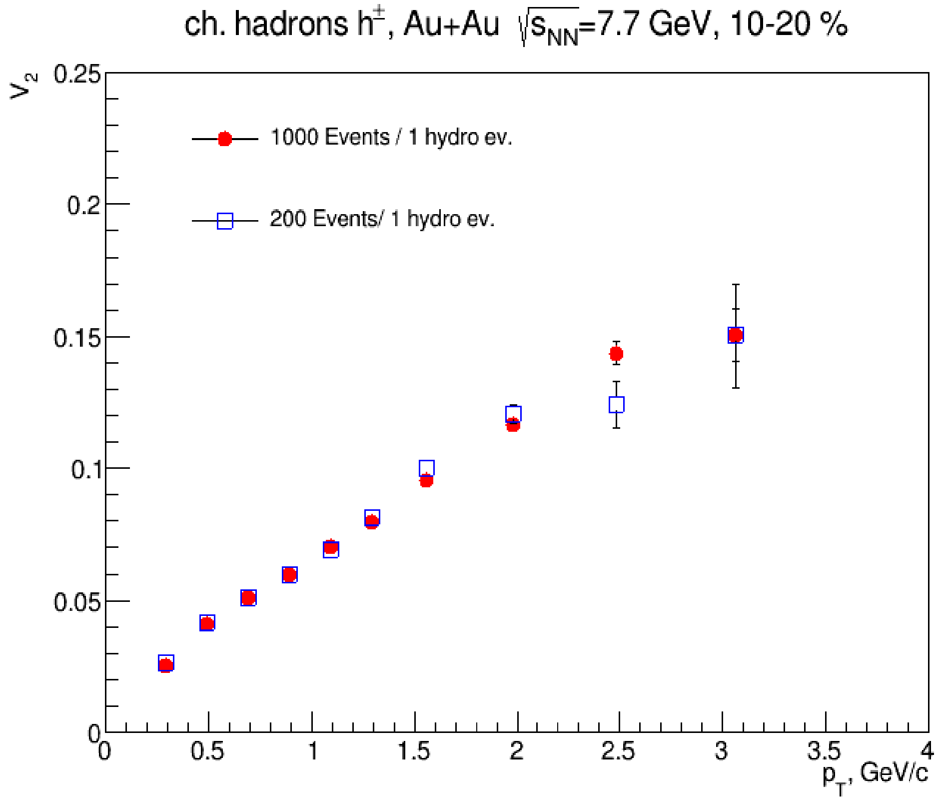


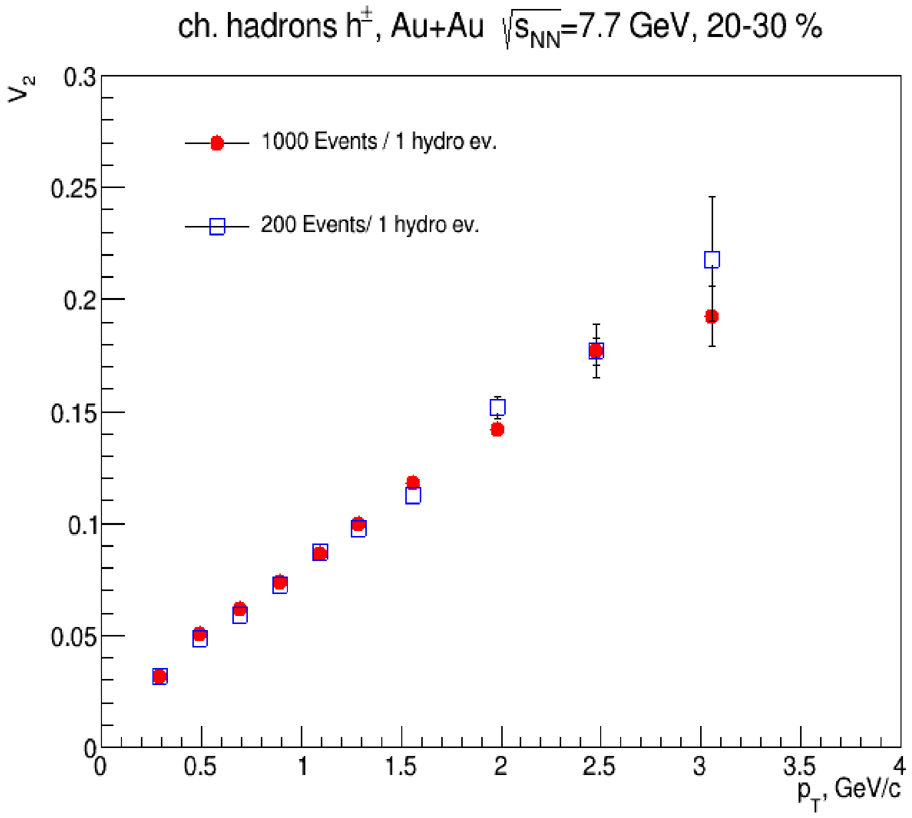
3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

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

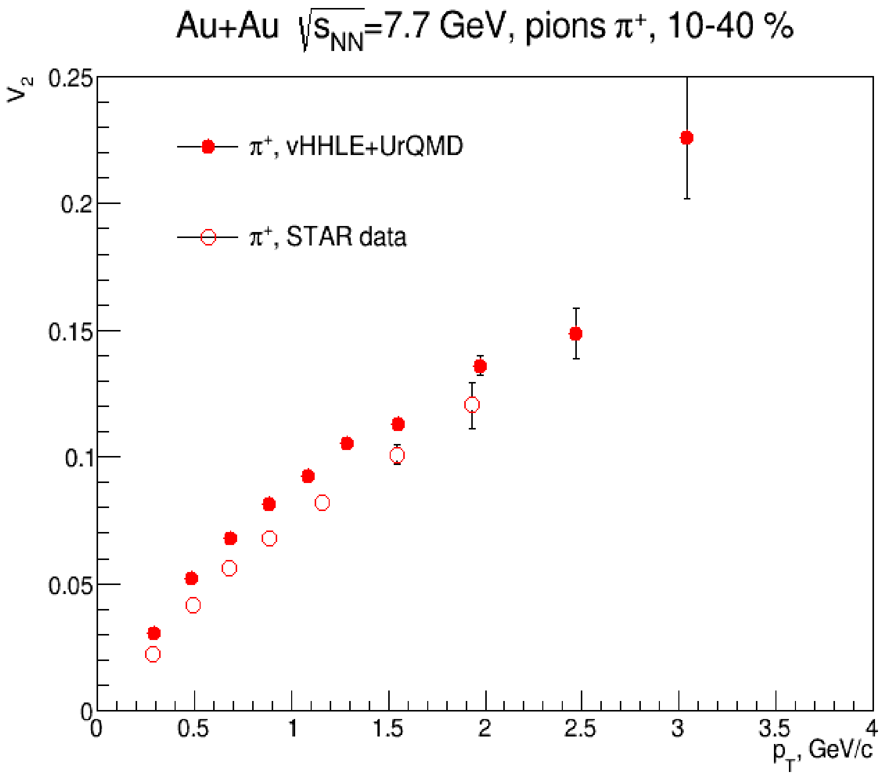
Good agreement with STAR published data

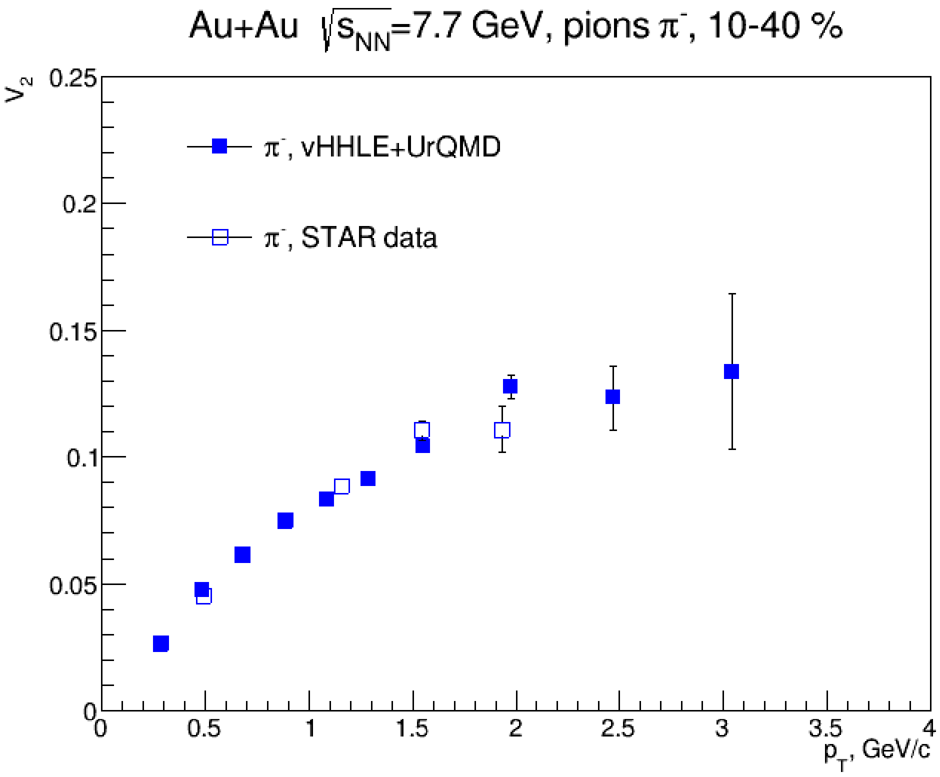
Differential elliptic flow: 3D hydro vHLLE + UrQMD





Differential elliptic flow of pions: 3D hydro vHLLE + UrQMD

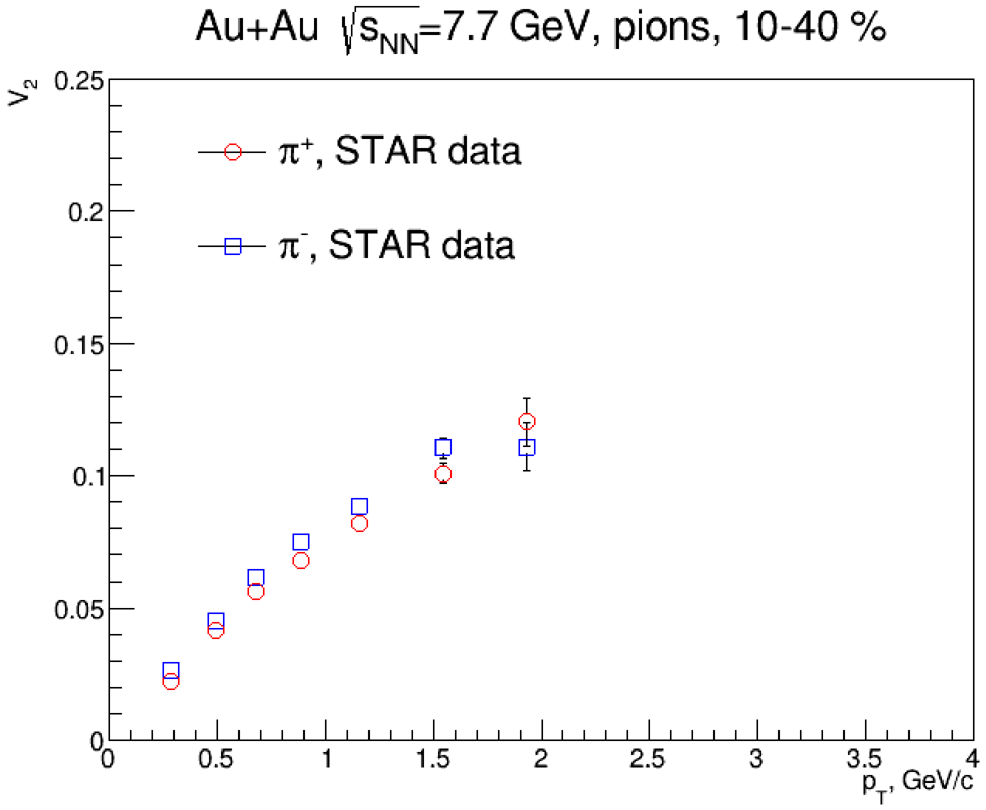


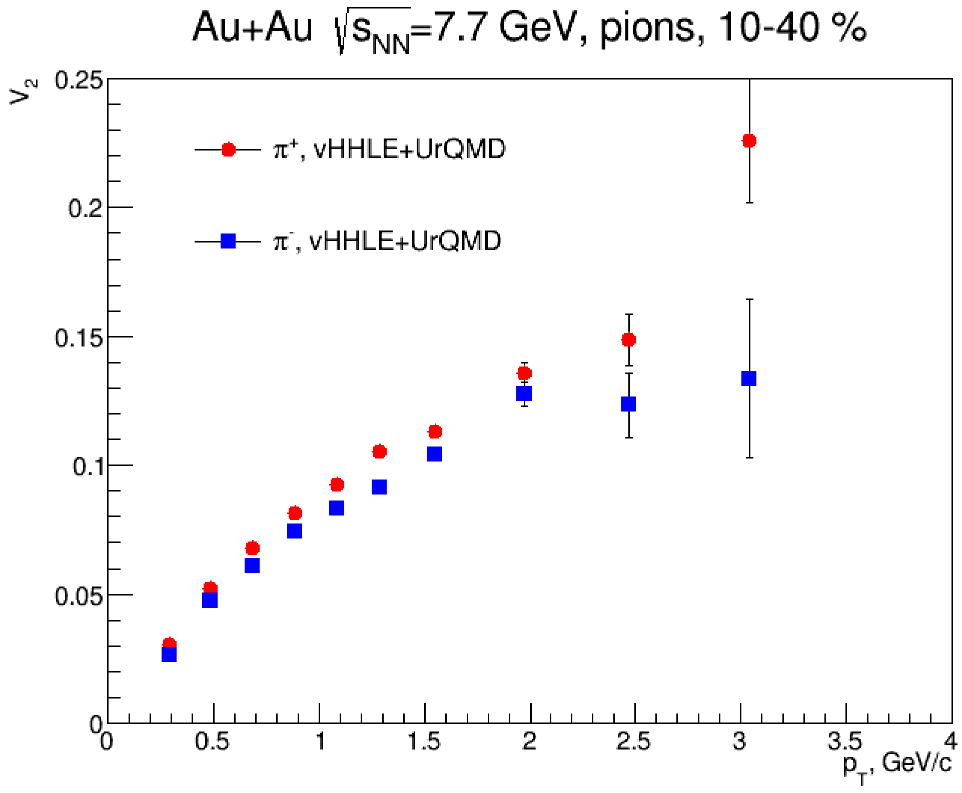


3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

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

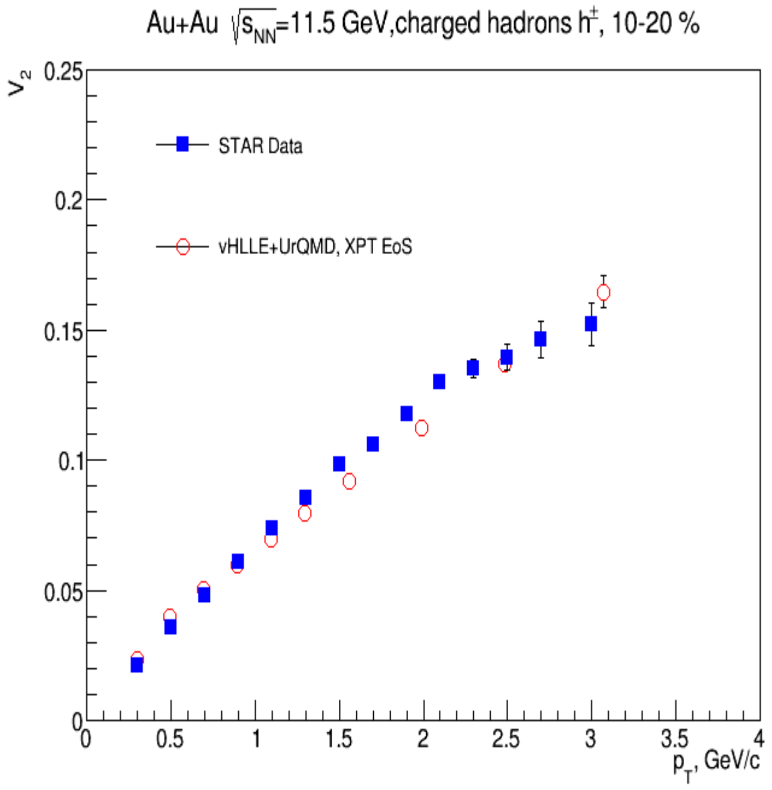
Differential elliptic flow of pions: 3D hydro vHLLE + UrQMD

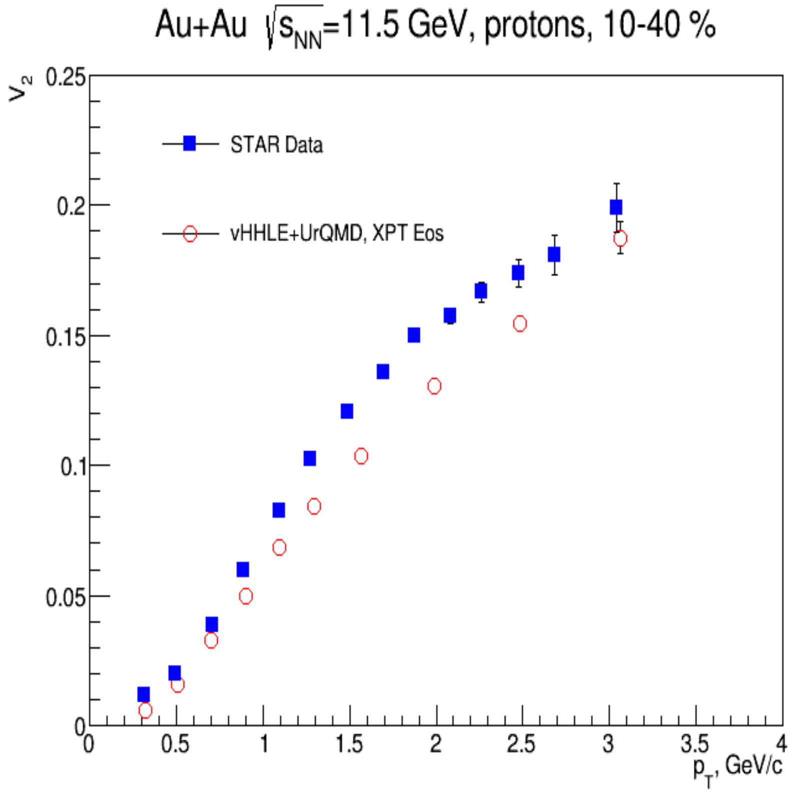




At NICA energies the elliptic flow if different for particles and anti-particles!

Differential elliptic flow: 3D hydro vHLLE + UrQMD



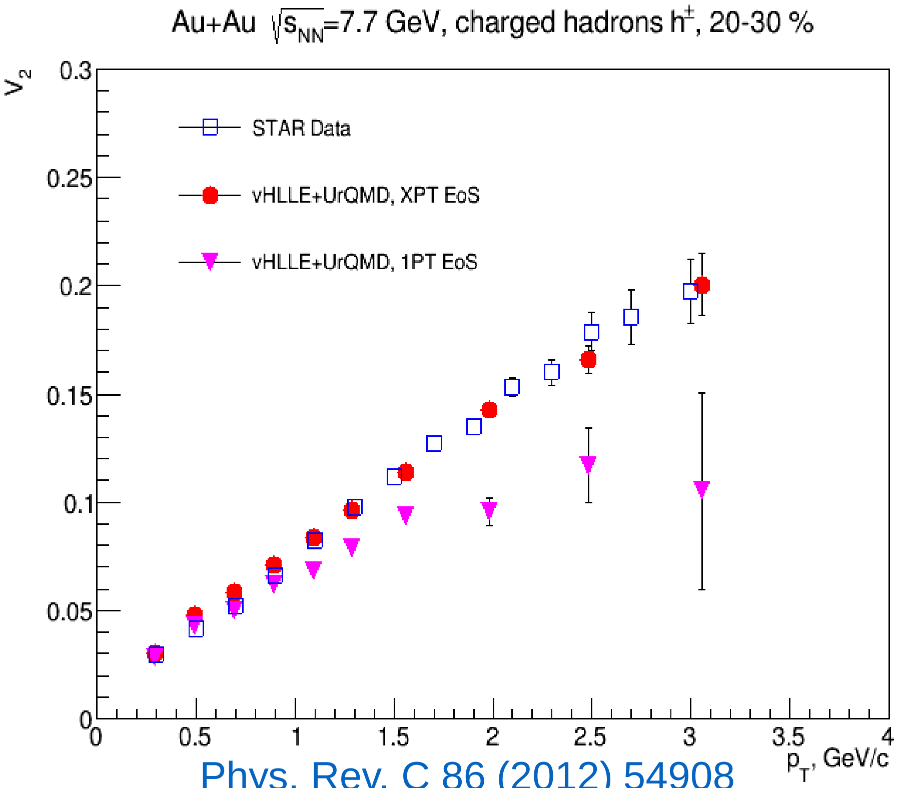


3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

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

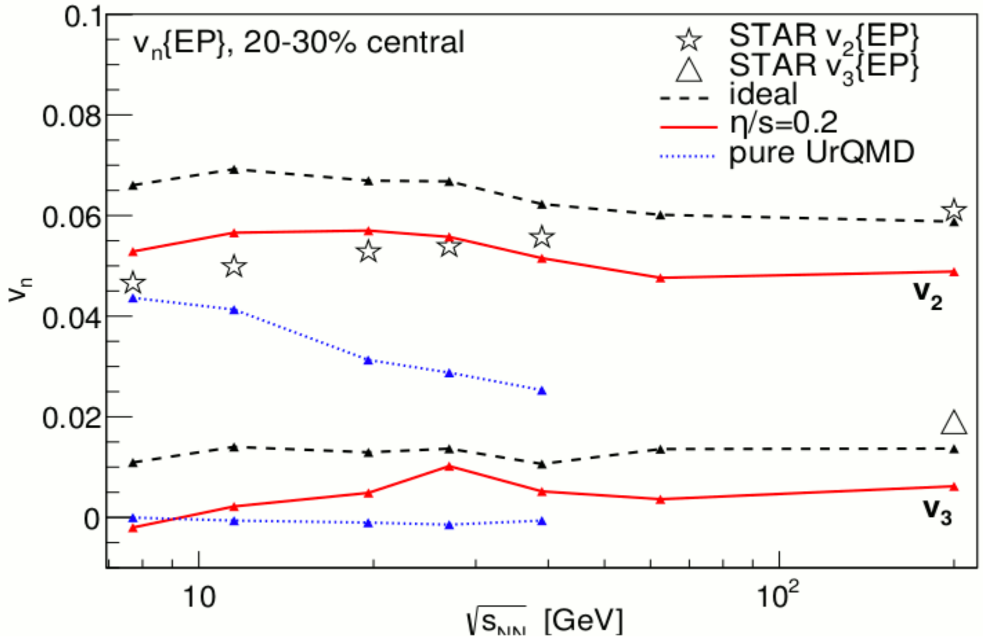
Reasonable agreement with STAR published data – need tuning ?

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

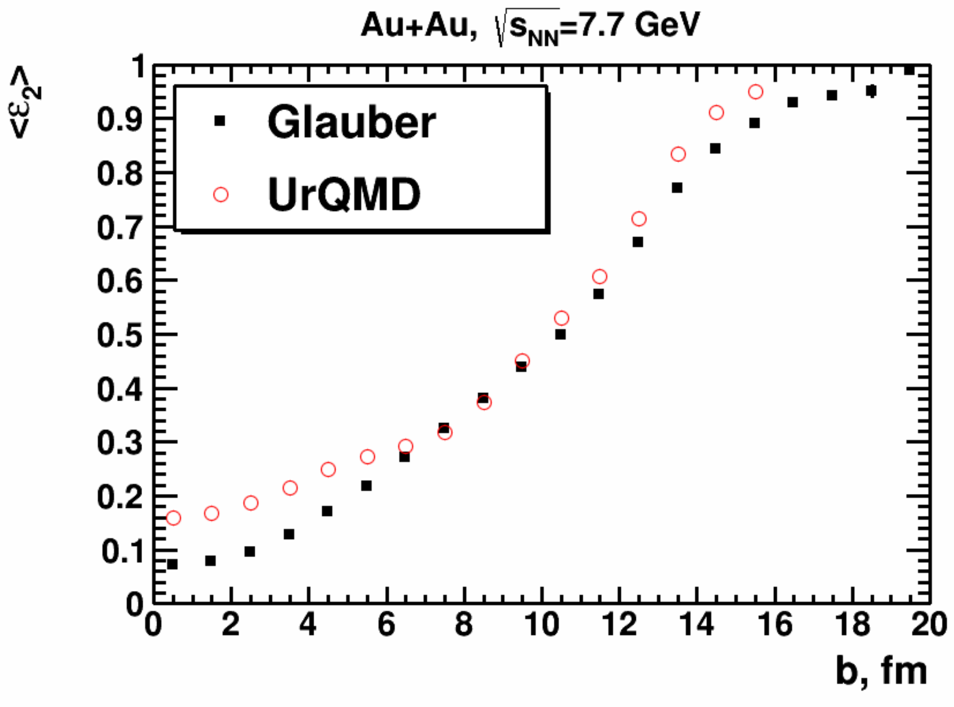


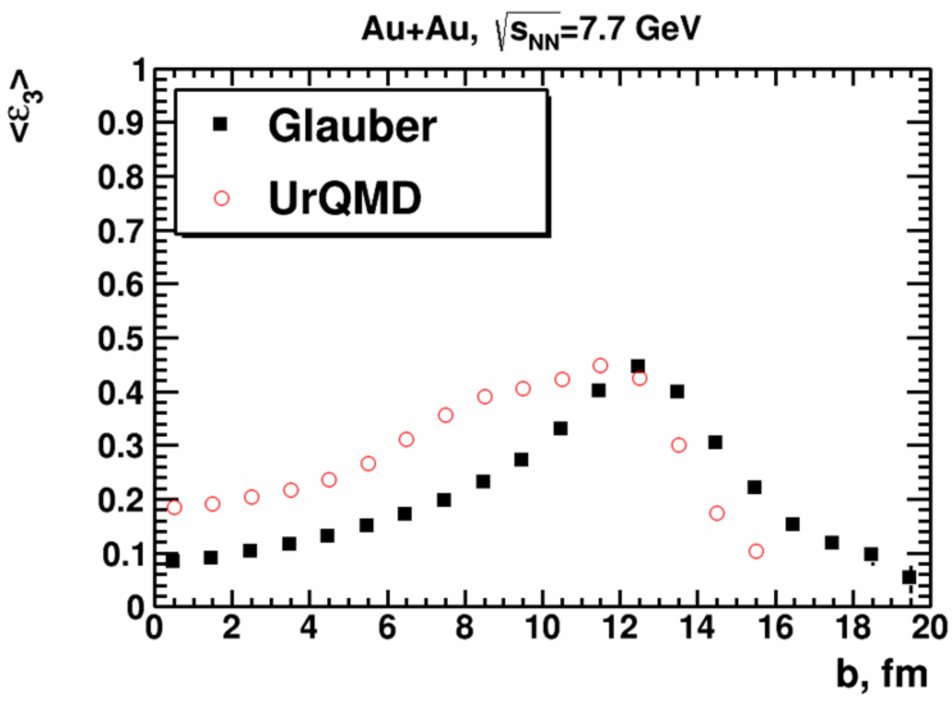
3D hydro model vHLLE + UrQMD (XPT EoS vs 1PT EoS) shows sensitivity of v_2 to the EoS

v_3=0 for pure UrQMD ??

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

Eccentricity: Comparison w/ UrQMD

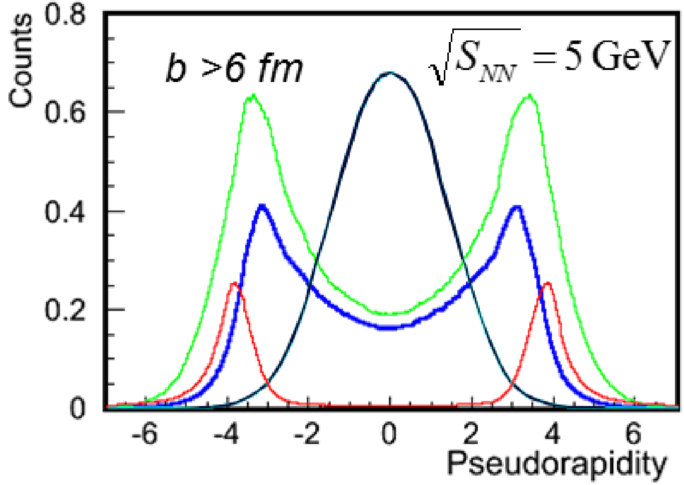


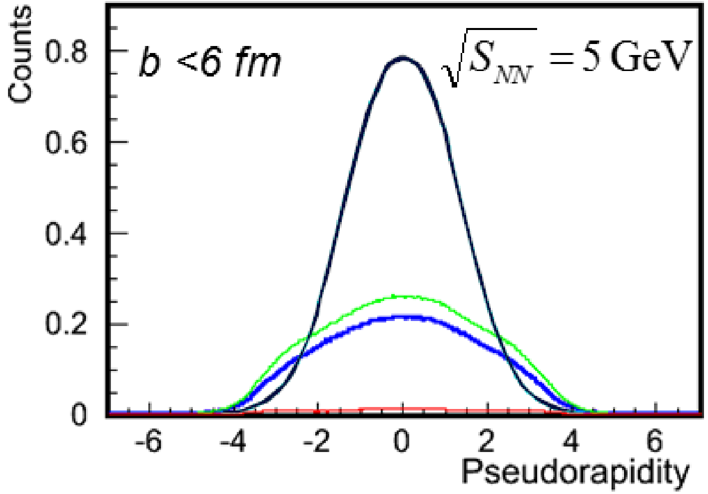


Notable difference between MC Glauber and UrQMD eccentricities

Common data format for all models : UrQMD, SMASH, PHSD, JAM, AMPT

FHCal and TPC acceptance





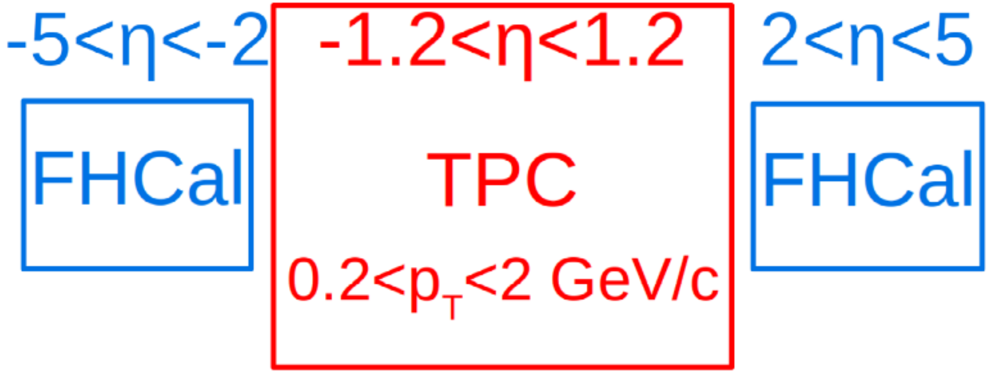
Pions

Neutrons

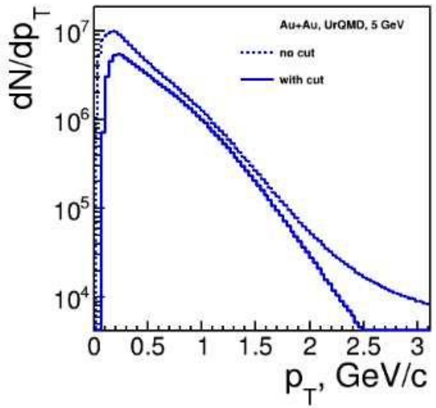
Protons

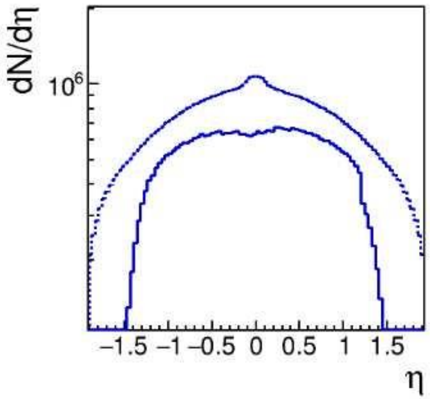
Fragments

- **TPC** - charged particles at midrapidity (particip
- **FHCal** - hadrons at forward rapidity (spectators

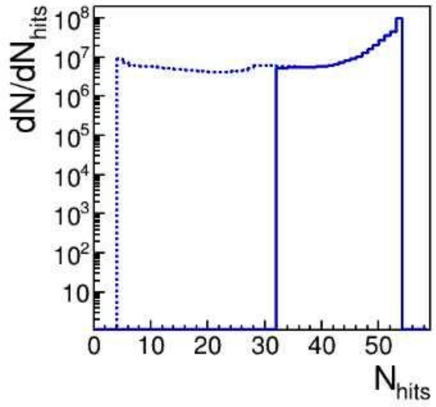


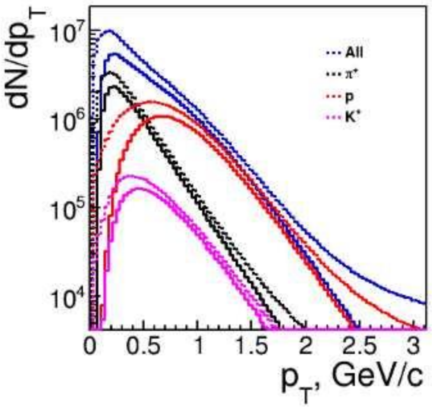
Track selection

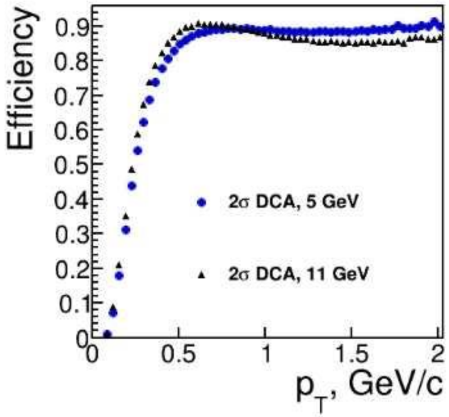




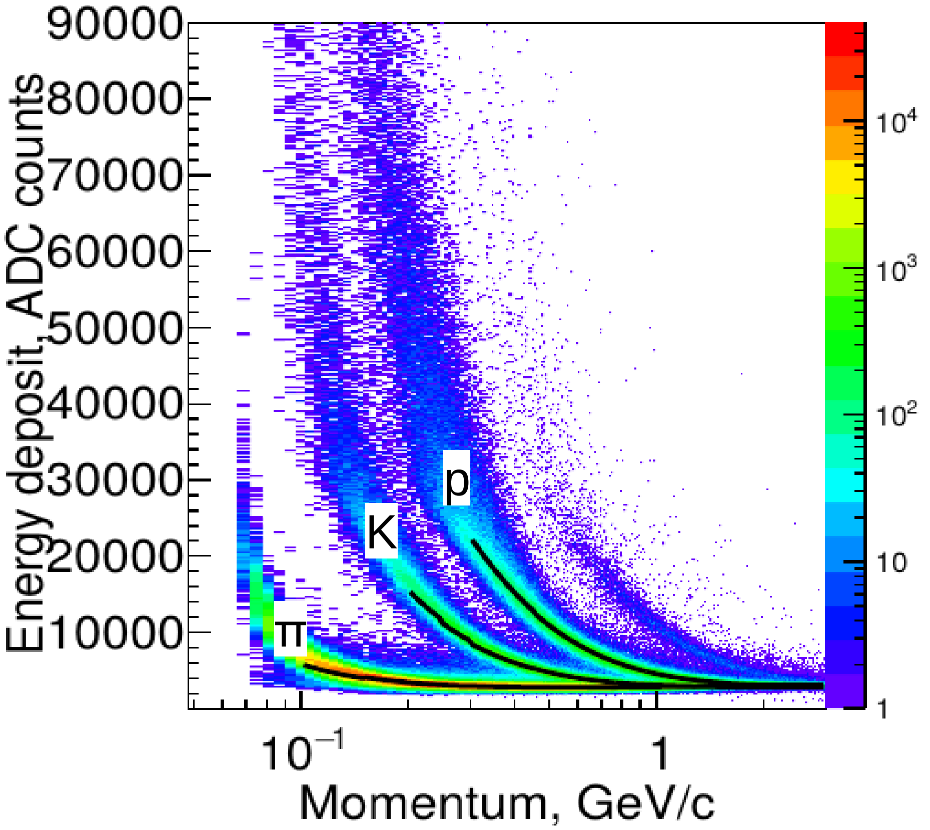
- $N_{TPC\ hits}$ >32
- $|p_T|$<3
- $|\eta|$<1.5
- PID based on TPC+TOF (MpdPid)





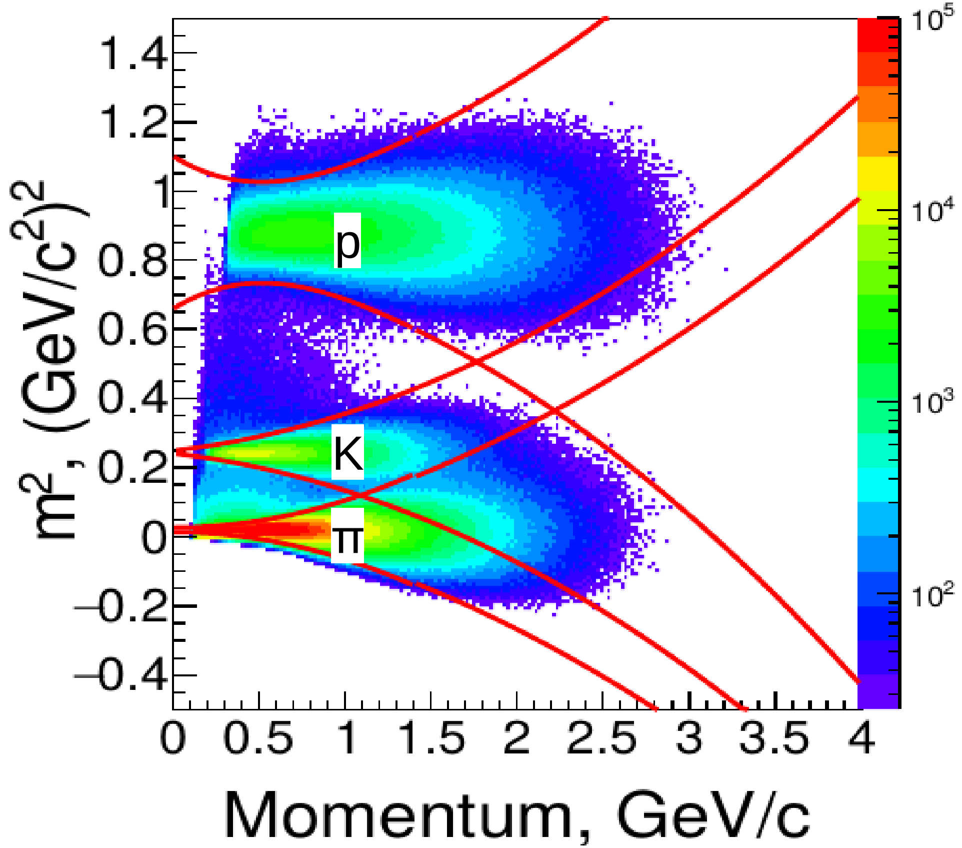


Particle identification based on TPC + TOF



Low momentum:

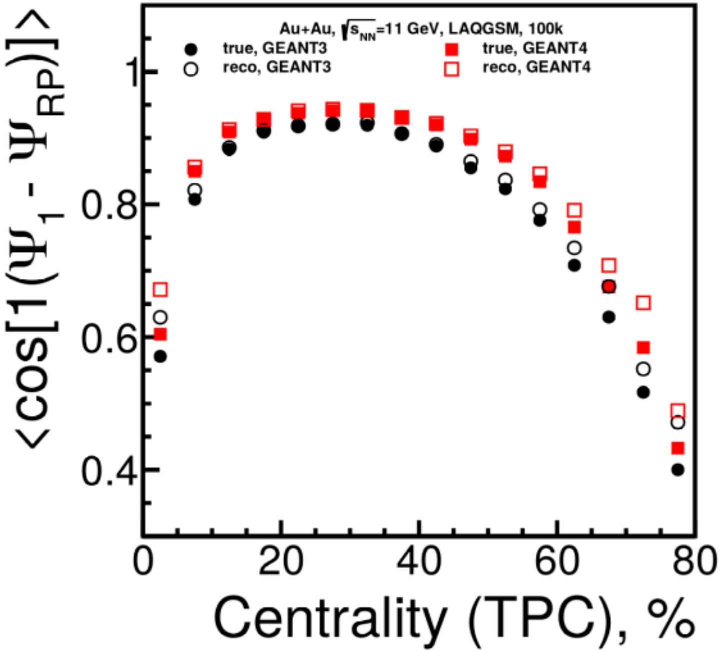
dE/dx from TPC

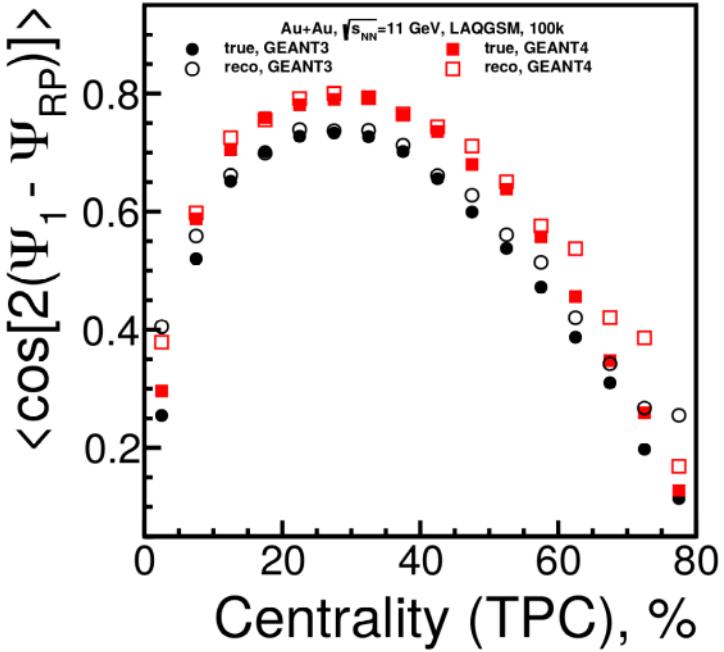


High momentum:

m^2 estimated from TOF signal

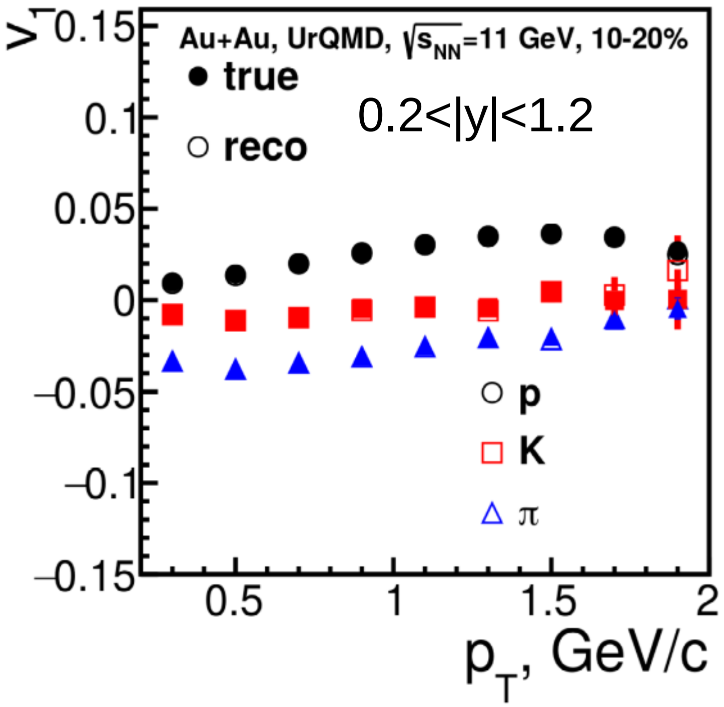
Resolution correction factor: GEANT3 vs GEANT4 comparison

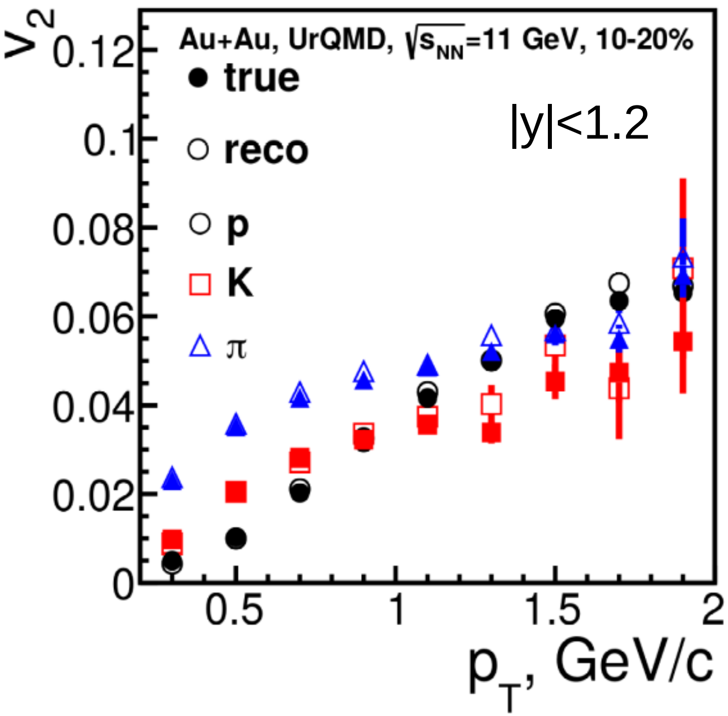




GEANT4 has more realistic hadronic shower simulation

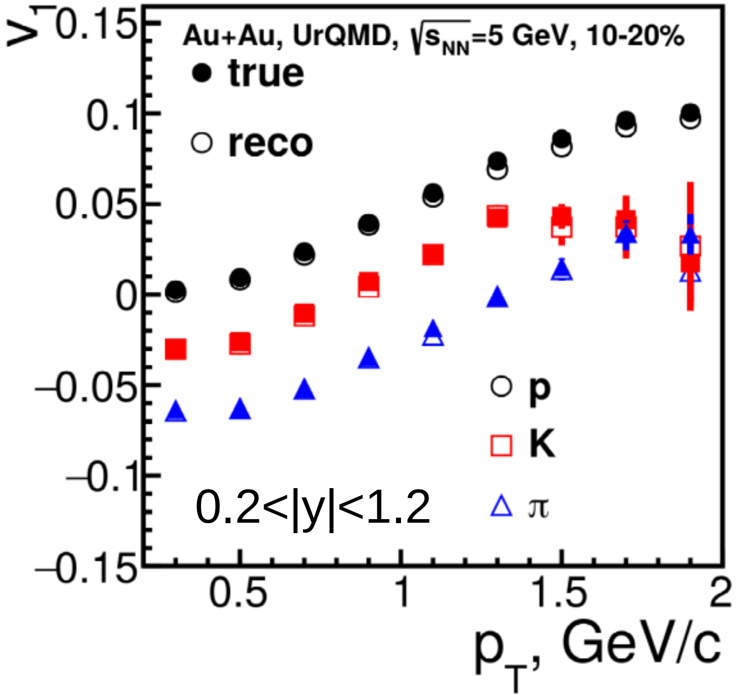
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

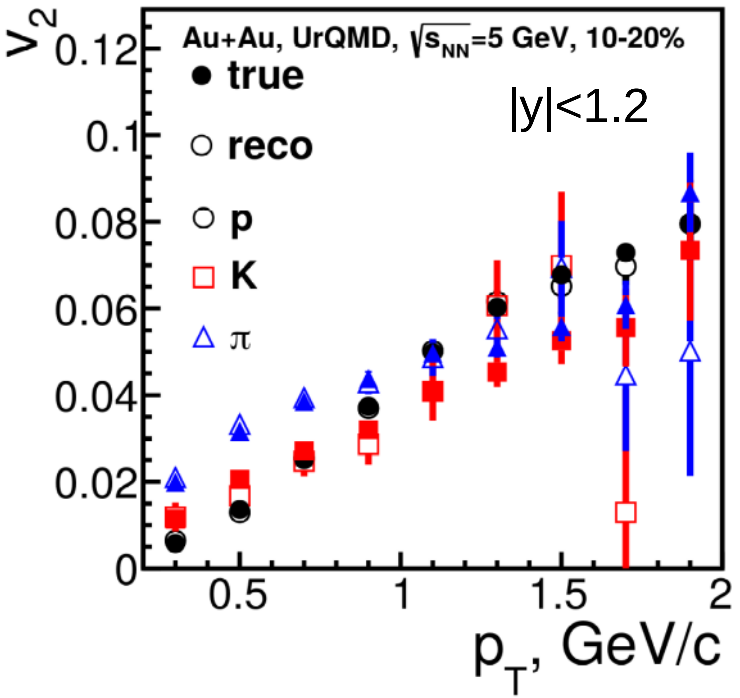




nd elliptic flow results after reconstruction and resolution correction are consistent to that o

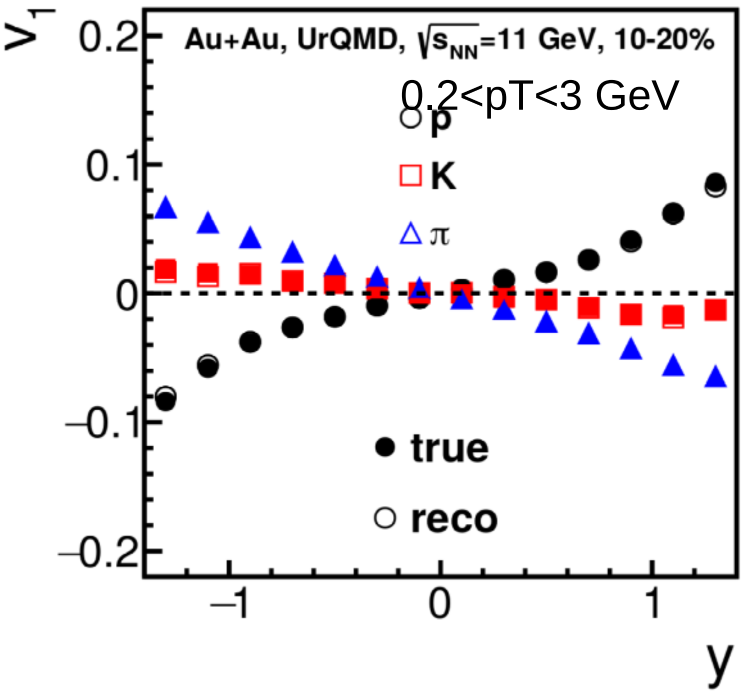
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV

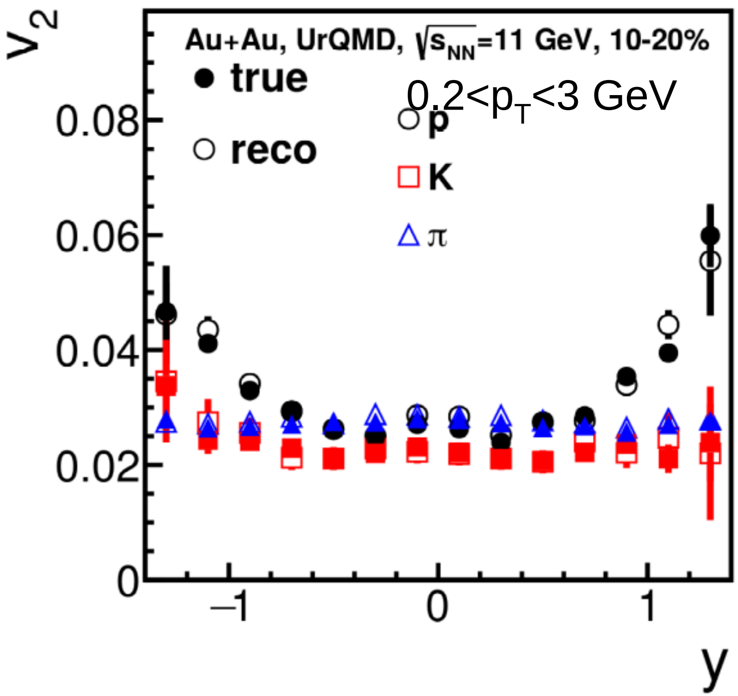




nd elliptic flow results after reconstruction and resolution correction are consistent to that o

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





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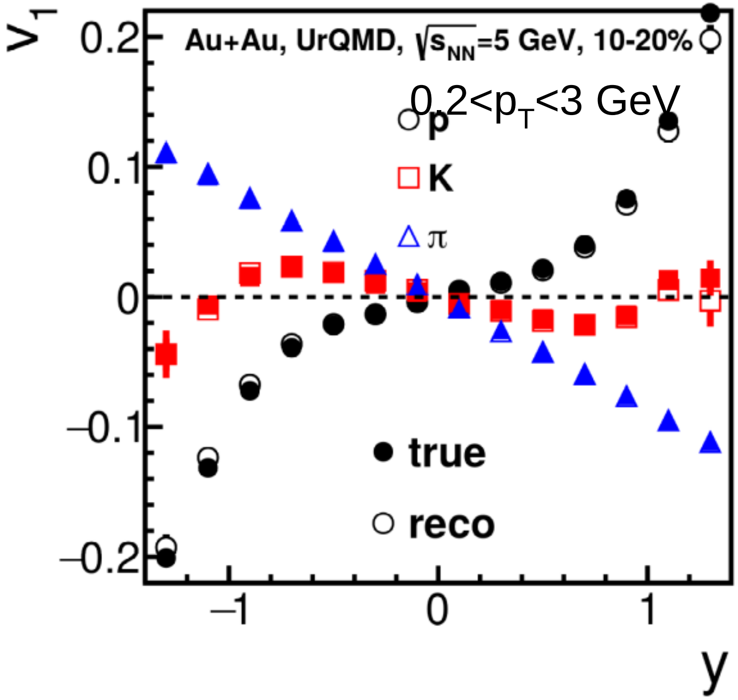
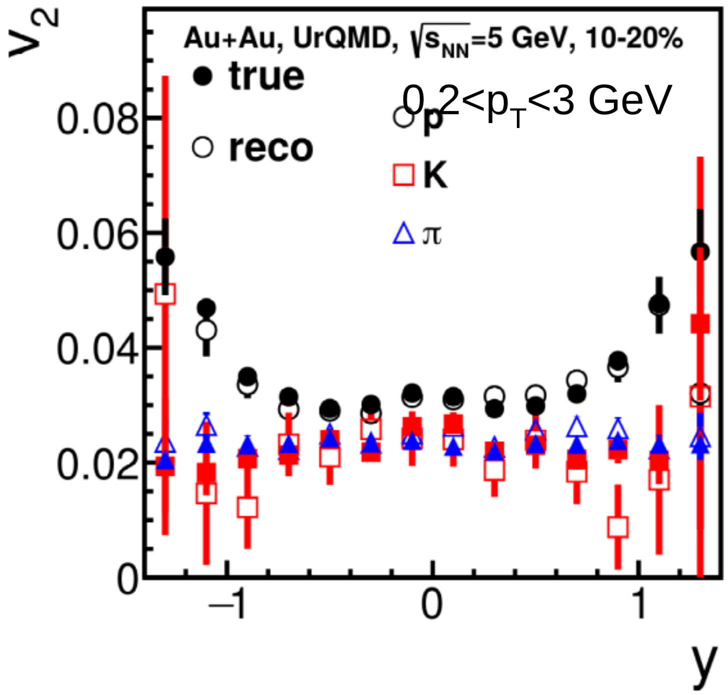
$v_{1,2}$ (y), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV





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