# Flow performance studies with MPD (NICA)

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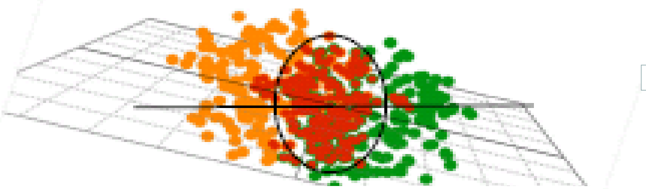
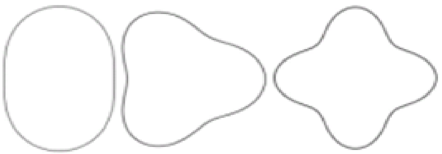
with big help from Pavel Batyuk (JINR)

NICA days 2019 and 4th MPD Collaboration Meeting,
Warsaw, October 21-25,2019

Project supported by RFBR № 18-02-40086

# Anisotropic Flow at RHIC-LHC

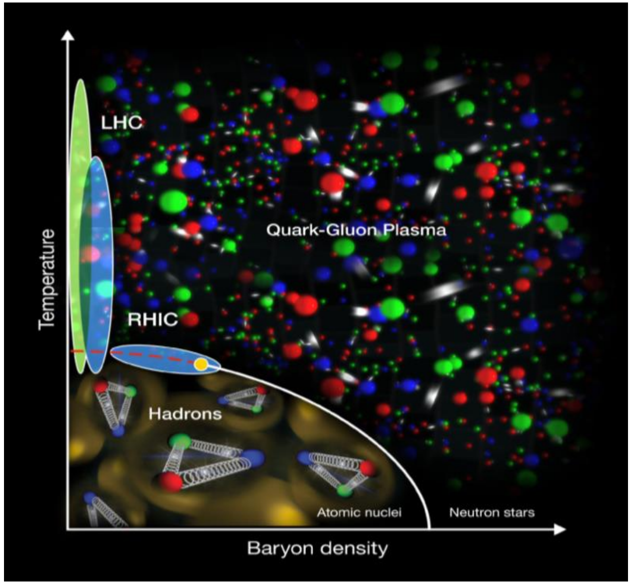




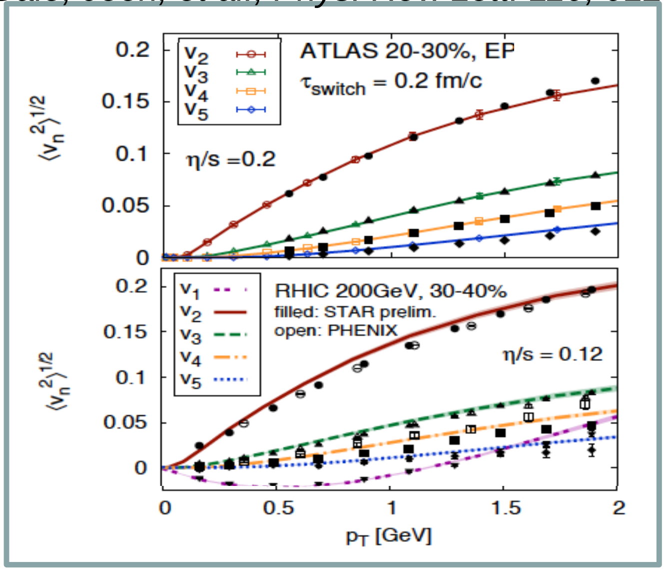

$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi\rangle + \langle r^n \sin n\phi\rangle}{\langle r^n\rangle}}$$

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

**Initial eccentricity (and its attendant fluctuations) $\varepsilon_n$ drive momentum anisotropy $v_n$ with specific viscous modulation**

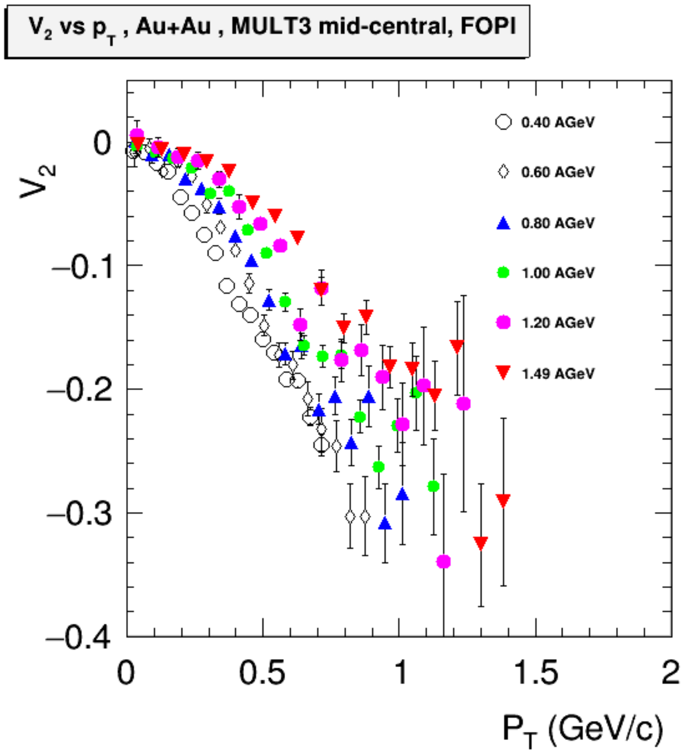



*Gale, Jeon, et al., Phys. Rev. Lett. 110, 012302*

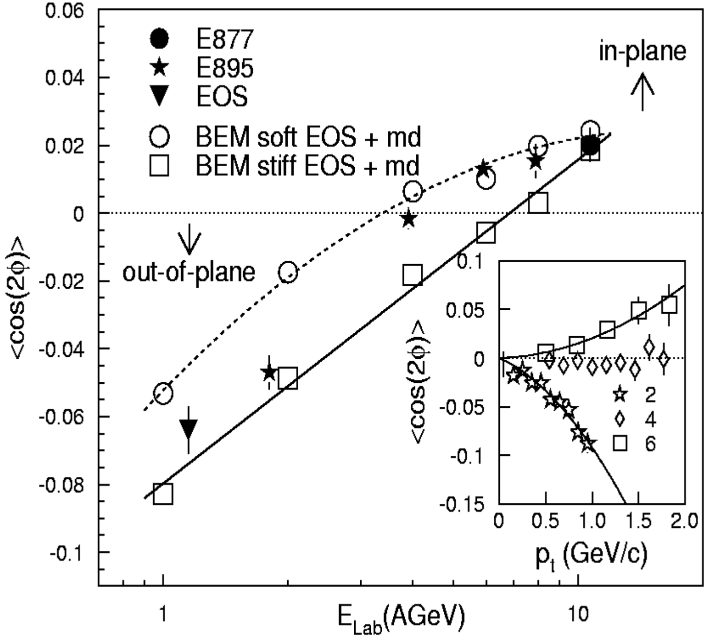


# Elliptic Flow at SIS-AGS: interactions with spectators

Phys.Lett. B612 (2005) 173-180 , FOPI




Phys. Rev. Lett. **83**, 1295 (1999). E895



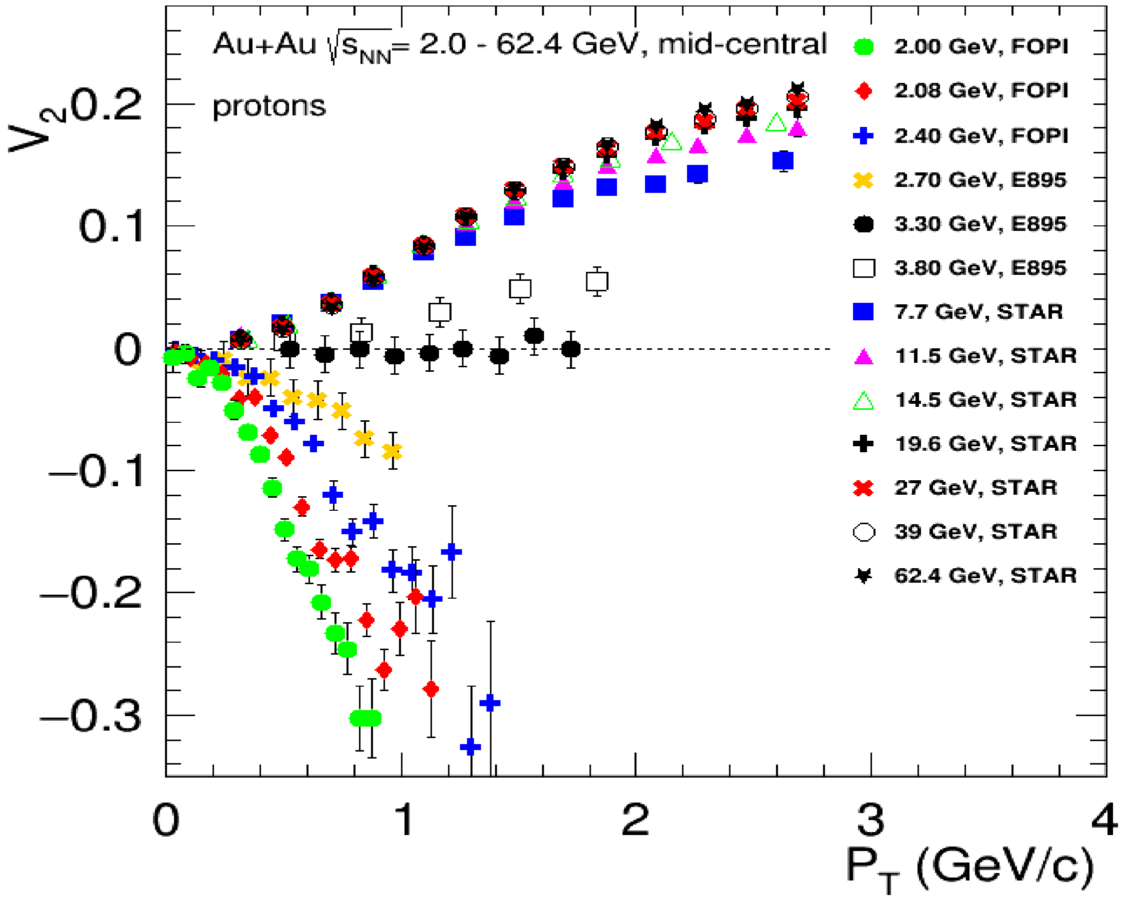

**Passage time: $2R/(\beta_{cm}\gamma_{cm})$**
**Expansion time: $R/c_s$**
**$c_s = c\sqrt{dp/d\varepsilon}$ - speed of sound**

**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**

# Excitation function of differential elliptic flow

EPJ Web Conf. 204 (2019) 03009

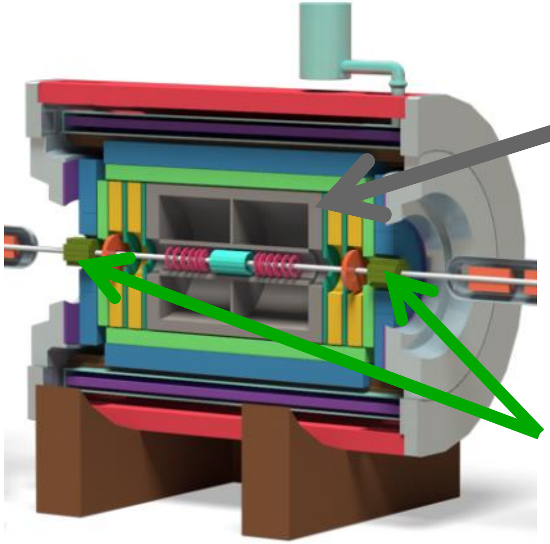
FOPI (15-29%)
E895 (12-25%)
STAR (10-40%)



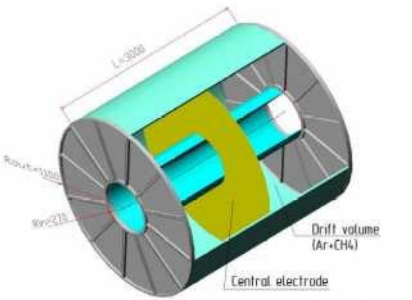

**High precision differential measurements of anisotropic flow?**

# Flow performance study at MPD (NICA)

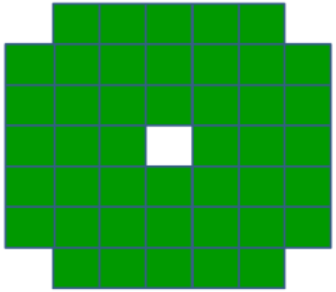
Multi Purpose Detector (MPD)



Time projection chamber (TPC)




Forward Hadron Calorimeter (FHCal)



**EP plane**

FHCal (2<|η|<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

$-5<\eta<-2$ FHCal

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

$2<\eta<5$ FHCal

# Setup, event and track selection

UrQMD
LAQGSM
→ GEANT4 → Reconstruction → Flow analysis

- Au+Au, $N_{events} = 4\cdot10^6$
- $\sqrt{s_{NN}}$ = 5 GeV
- $\sqrt{s_{NN}}$ =11 GeV

- TPC
- FHCal
- TOF
- ...

Event classification:
- Track multiplicity
- FHCal energy

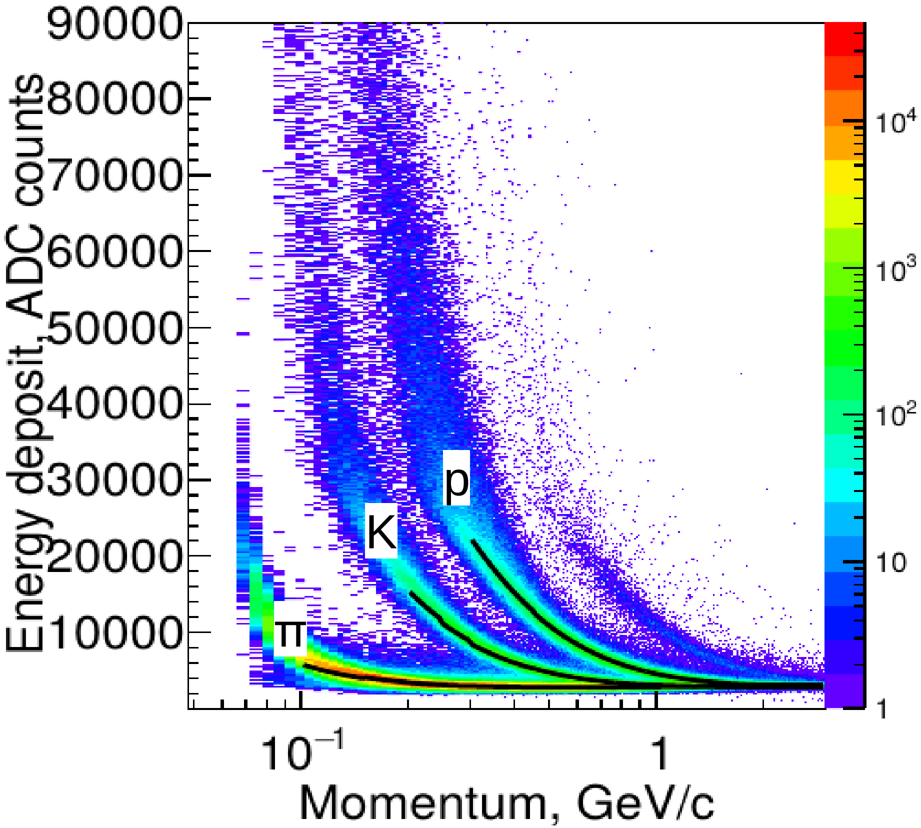
Track selection:
- Primary tracks (2σ DCA cut)
- $N_{TPC\ hits}$ > 32
- $p_T$>0.2 GeV/c
- |η| < 1.5
- PID based on TPC+TOF (MpdPid)


NICA
Technical Design Report
for the MPD Experiment
Nuclotron Based Ion Collider Facility
Forward Hadron Calorimeter
(FHCal)
June 2018

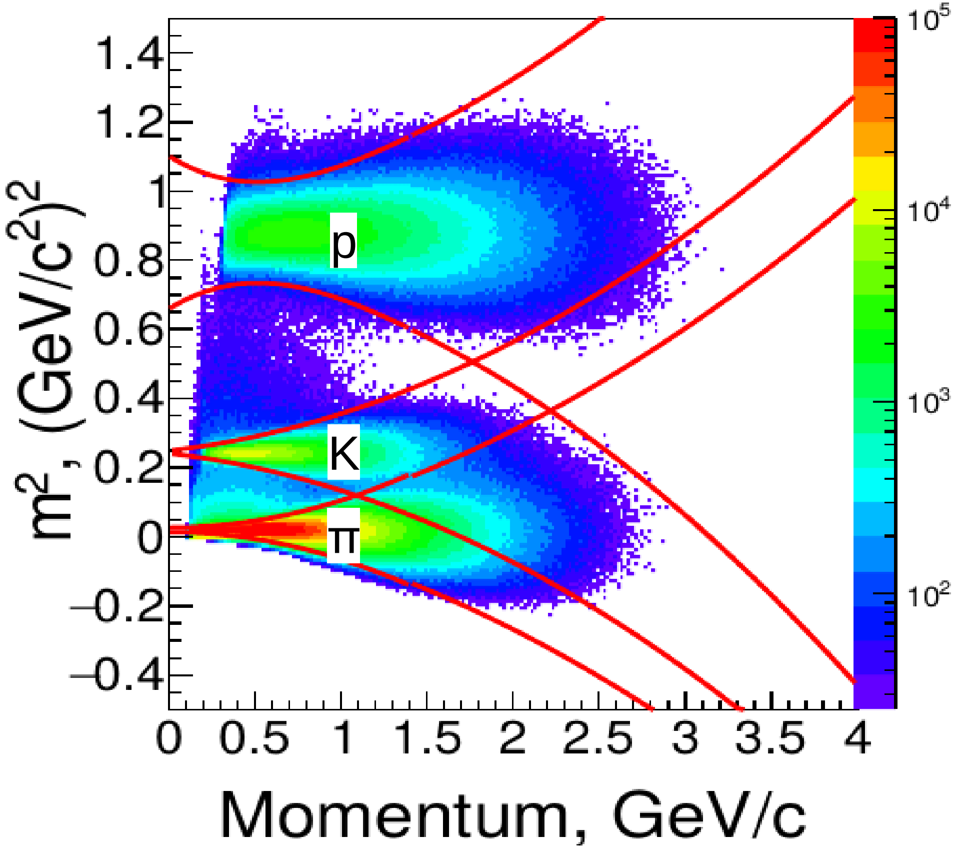
MPDRoot, June 2018

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

# Particle identification based on TPC + TOF

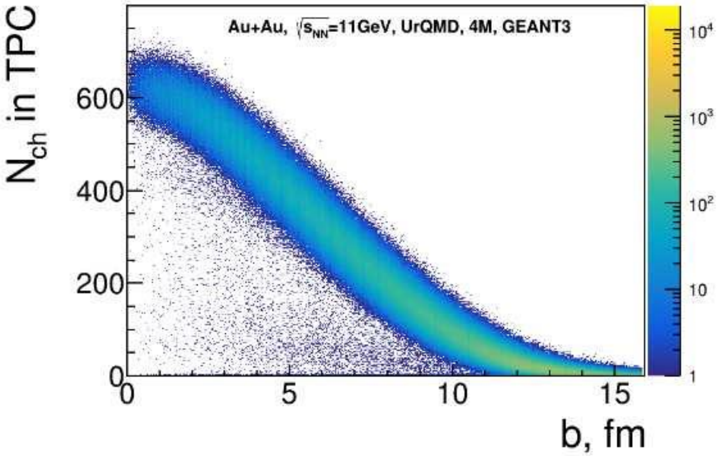


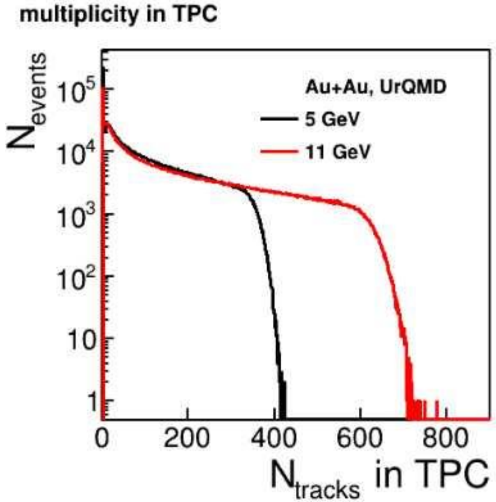

Low momentum:
dE/dx from TPC

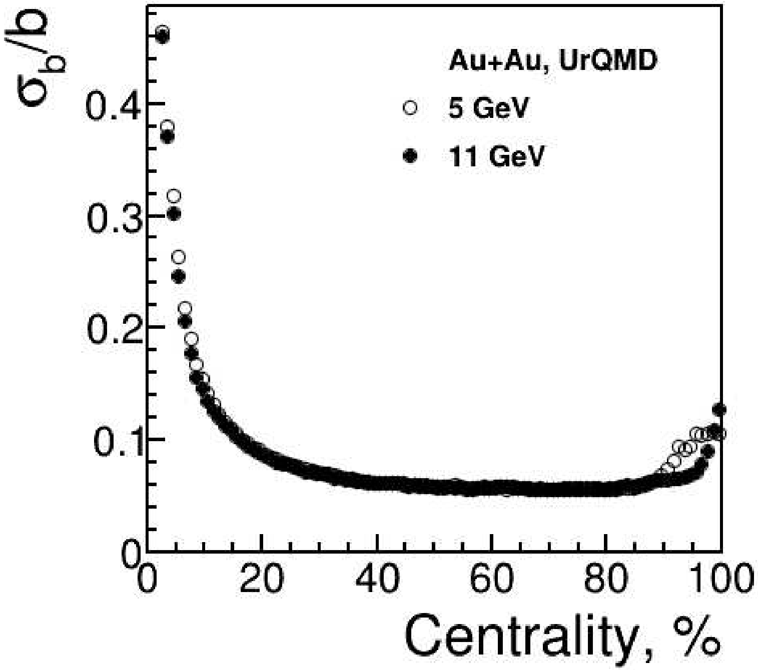



High momentum:
$m^2$ estimated from TOF signal

# 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 implementation in MPD (NICA)

Both left and right FHCal parts were used:

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

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

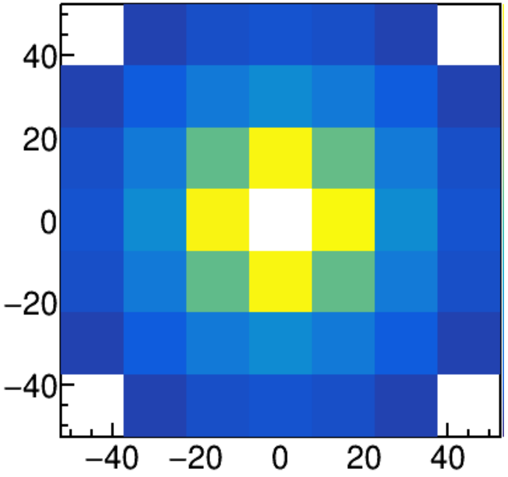
$$m = 1 \text{wasused}$$

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

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

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

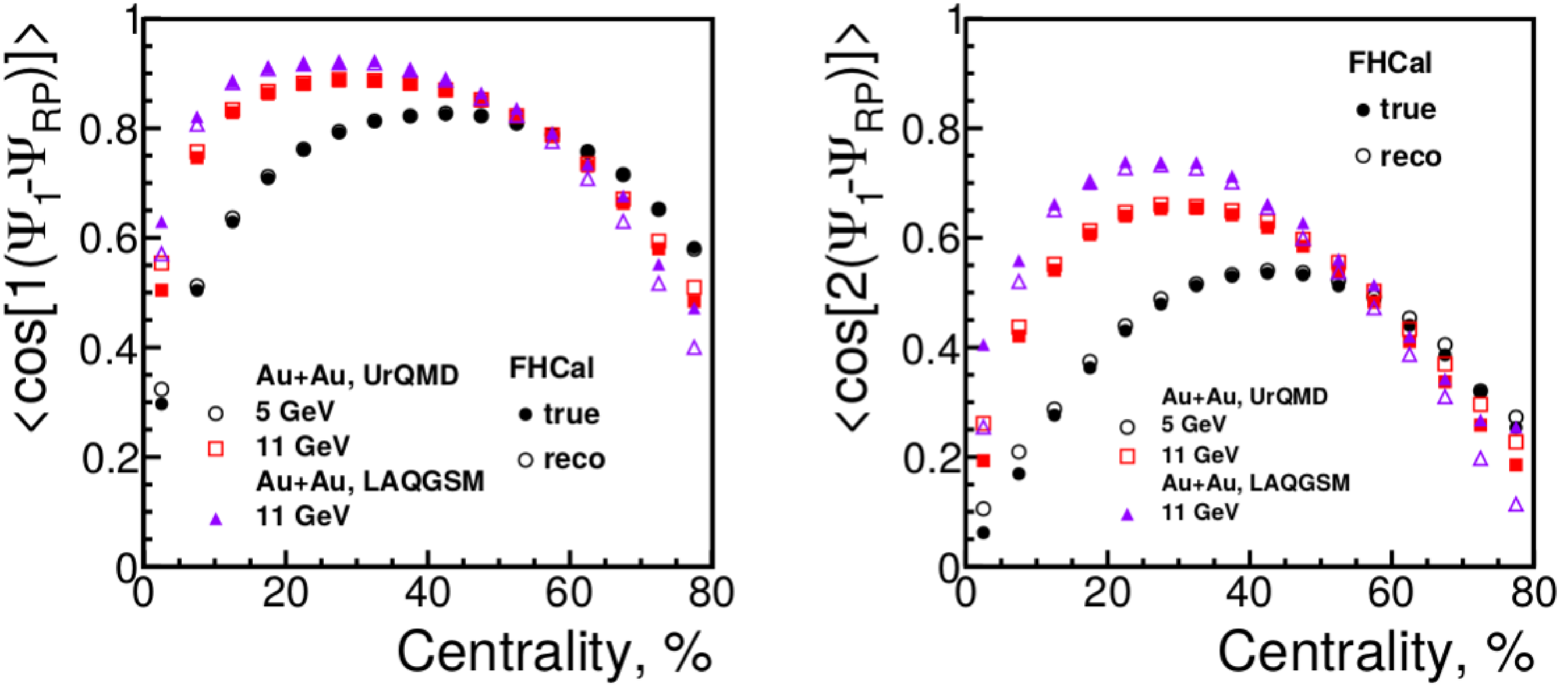
- $E_i$ is the energy deposition in *i-th* FHCal module
  $\varphi_i$ is its azimuthal angle.
- For *m=1* weights had different signs for backward and forward rapidity.
- Δη-gap>0.5 between TPC and FHCal suppresses non-flow contribution




Energy distribution in FHCal

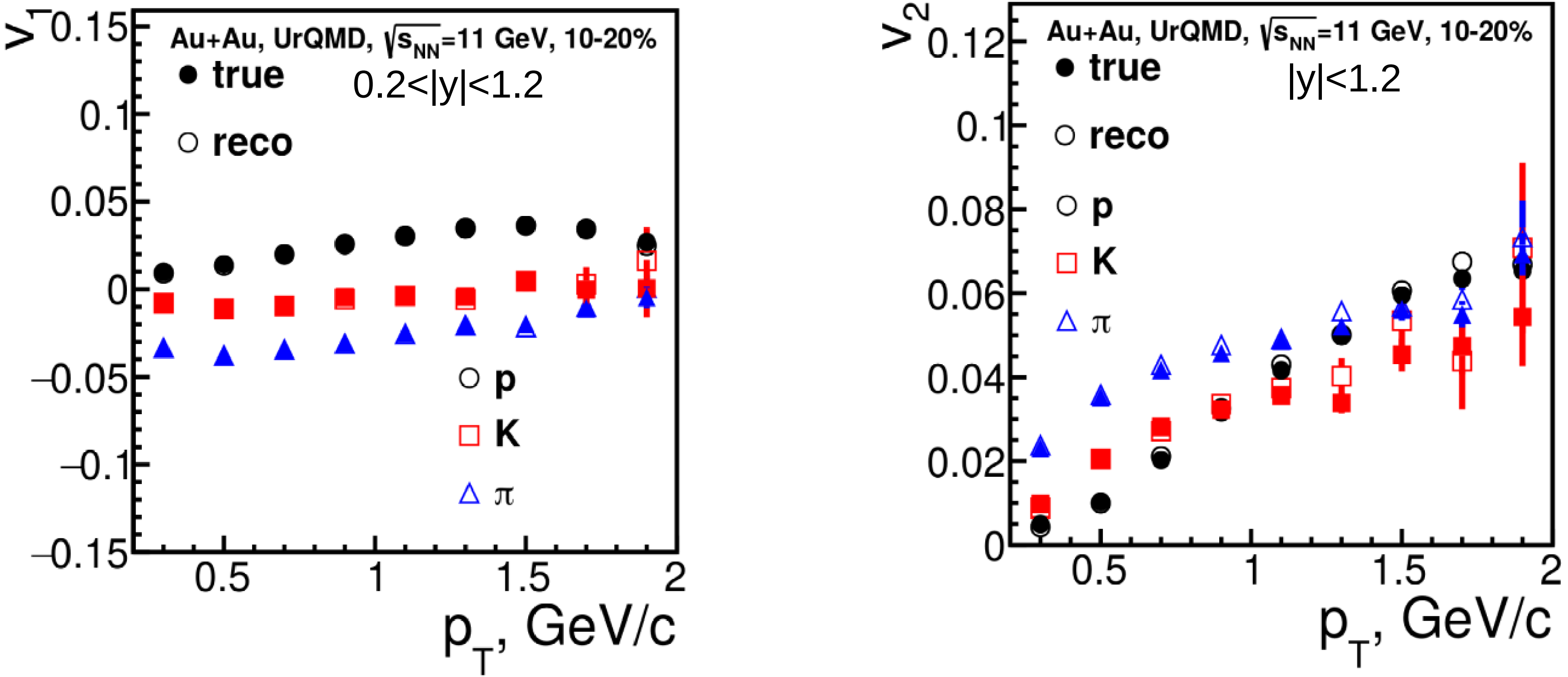
**https://git.jinr.ru/nica/mpdroot/tree/dev/macro/physical_analysis/Flow**

# Event plane resolution correction factors



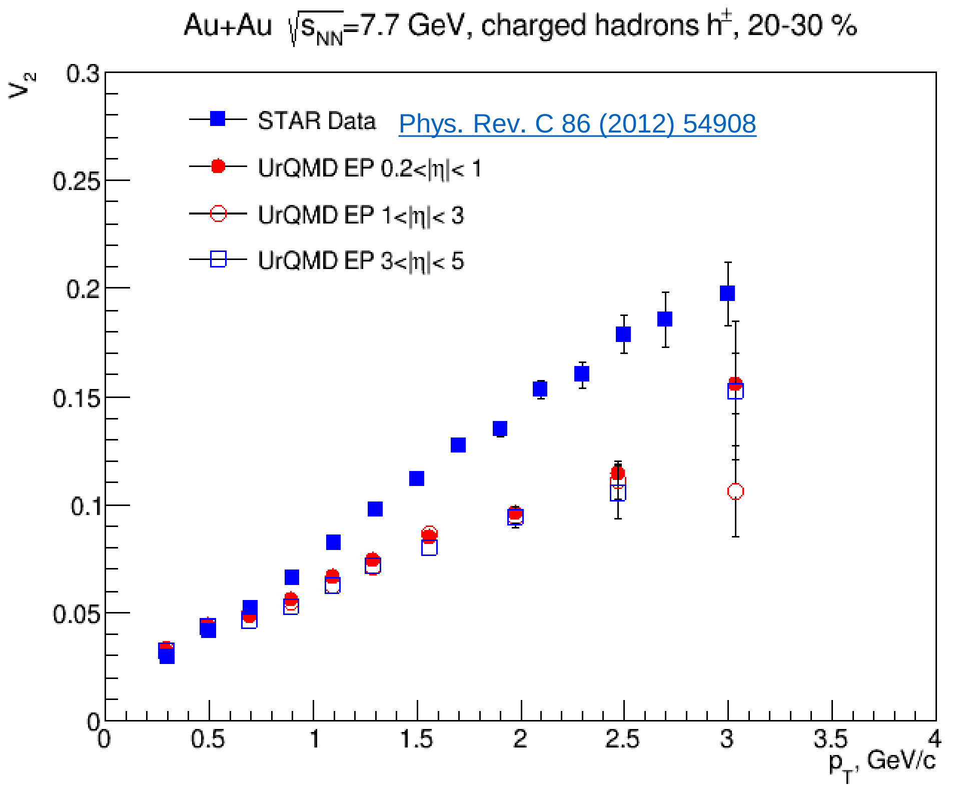

Good performance in the centrality range 0-80% for NICA collision energy range

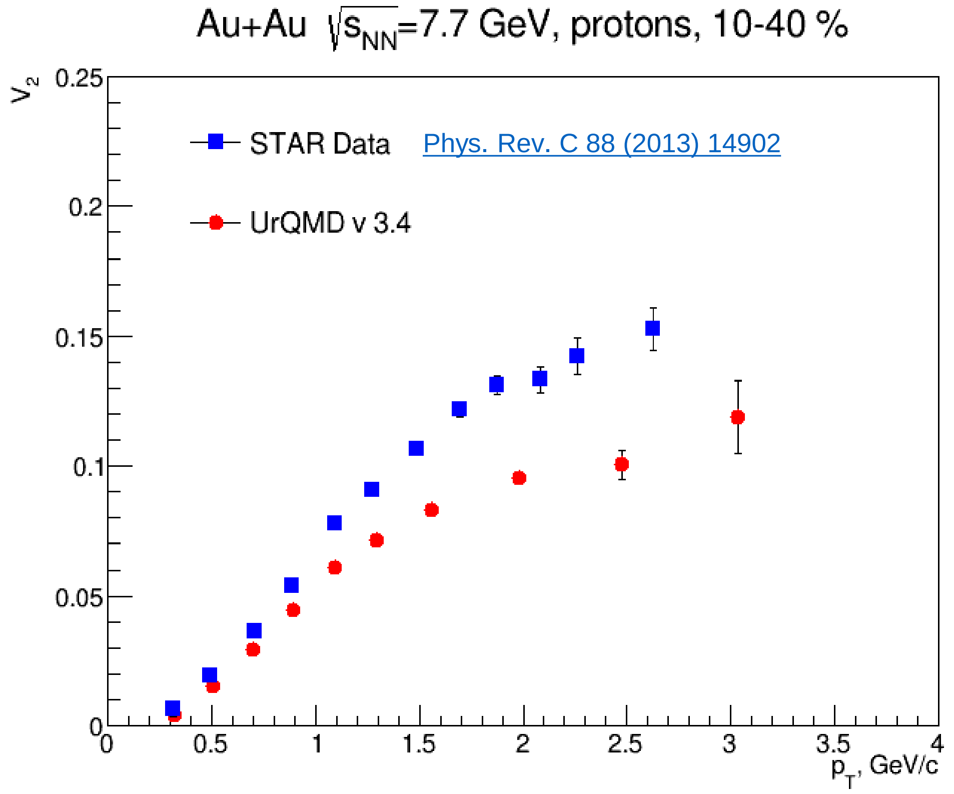
# $p_T$-dependence of $v_1$ and $v_2$ of reconstructed signal




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

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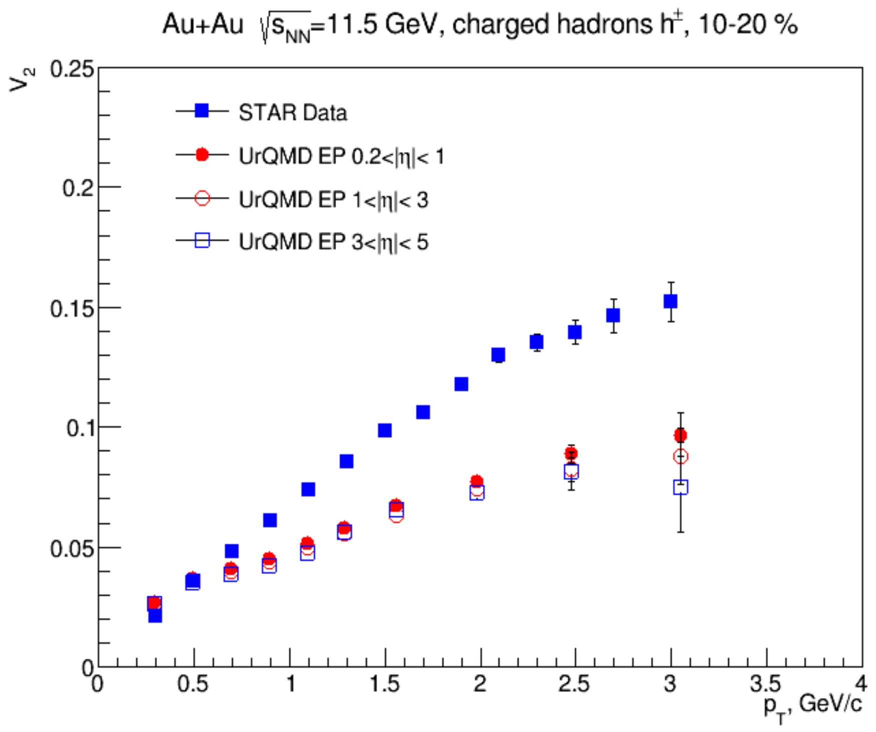
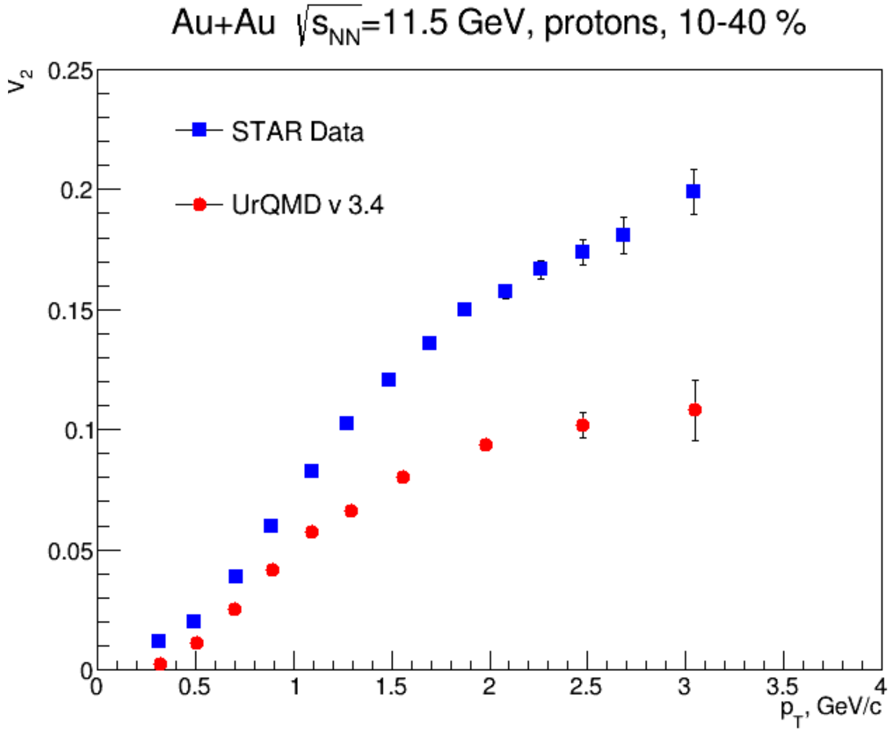
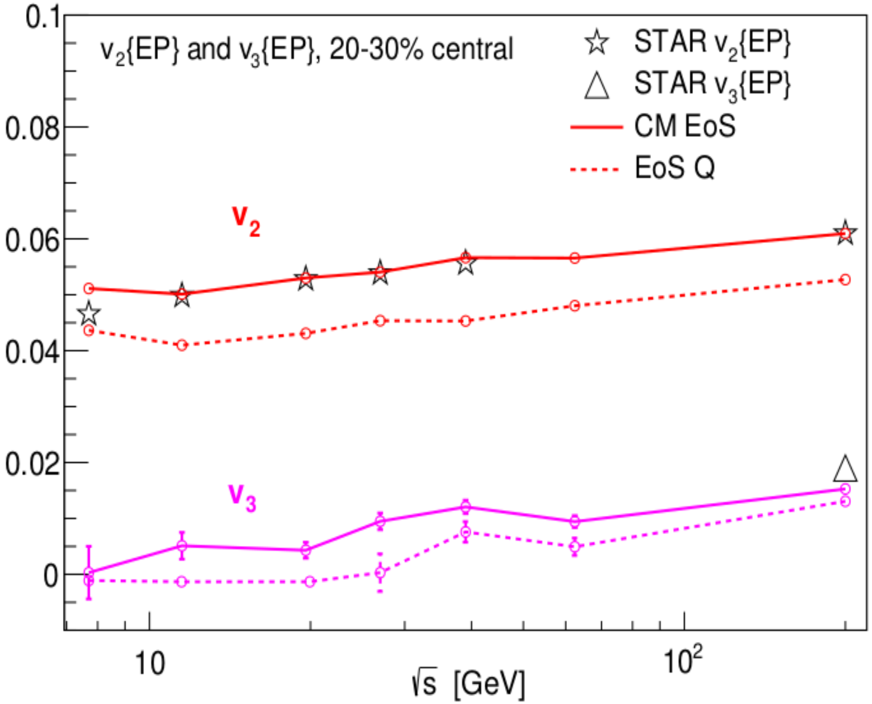


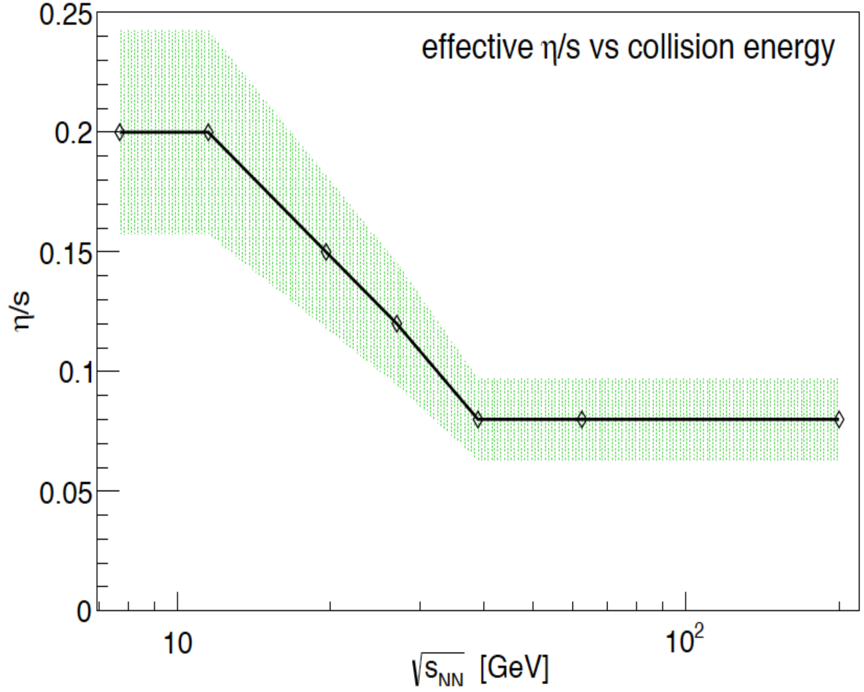




What about other "hadronic" models: SMASH, JAM, HSD? - Under investigation

# Elliptic and triangular flow of charged hadrons at RHIC BES

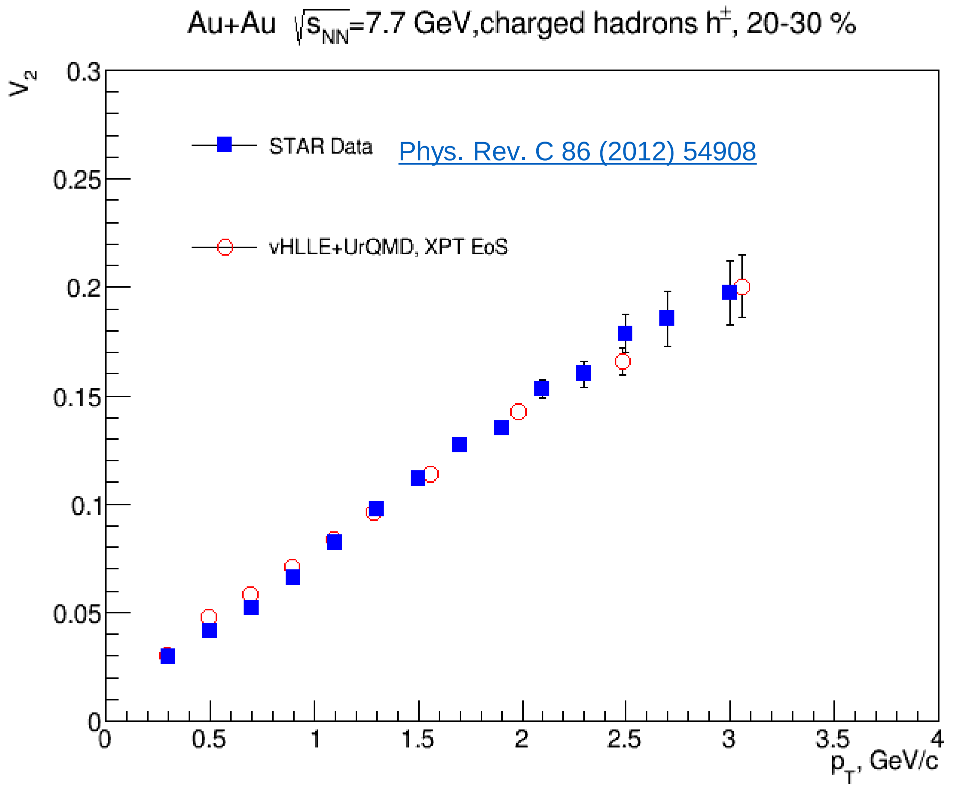
Iu.A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher, Phys.Rev. C91 (2015) no.6, 064901

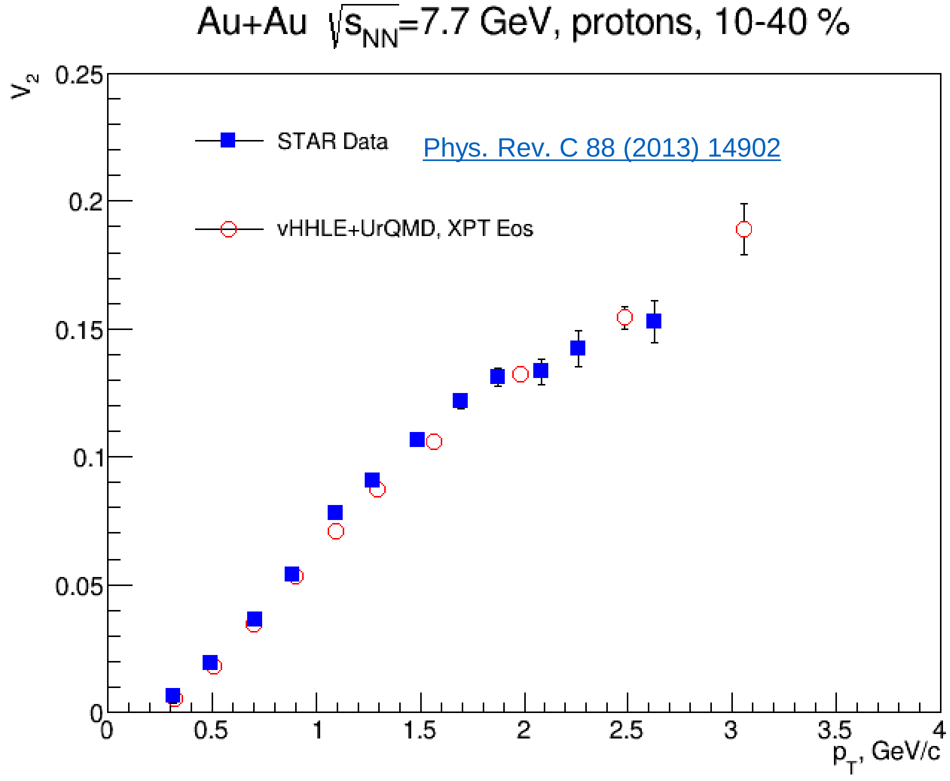



Hybrid model: UrQMD + 3D hydro model vHLLE + UrQMD
Shows good agreement with published STAR data for integrated $v_n(\sqrt{s_{NN}})$ from BES-I

# 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

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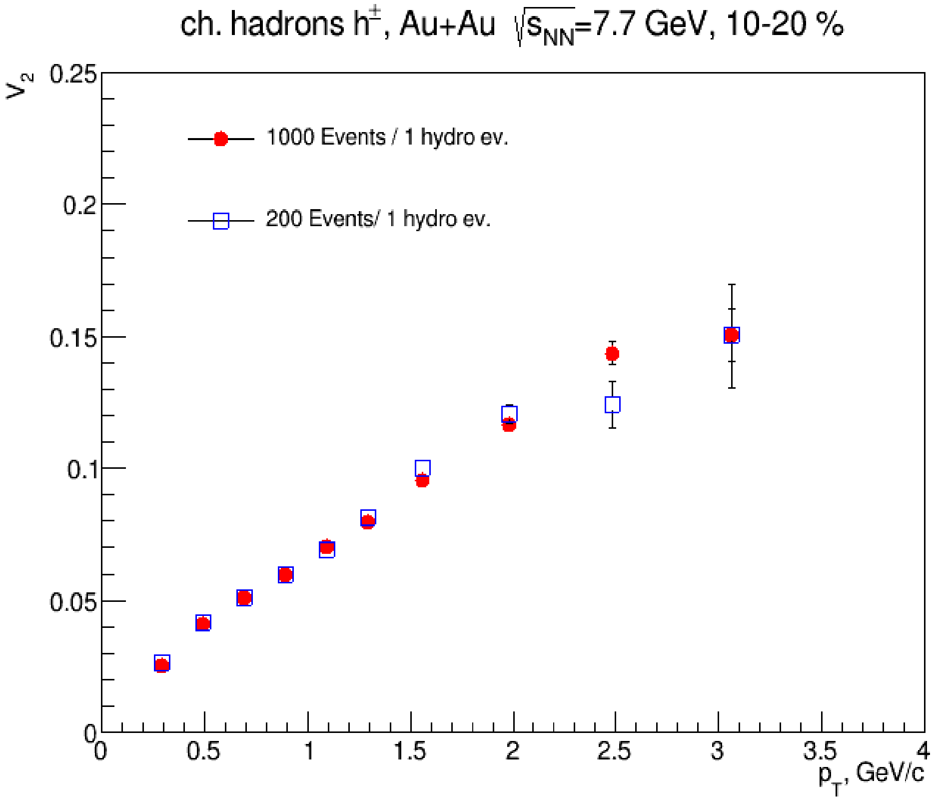
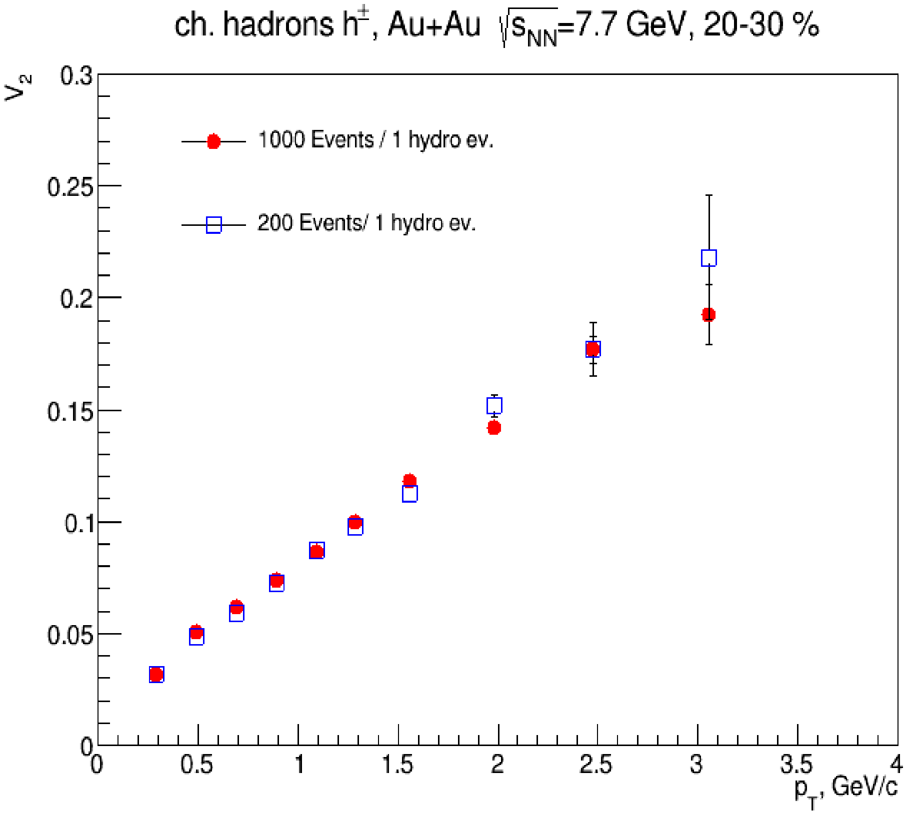
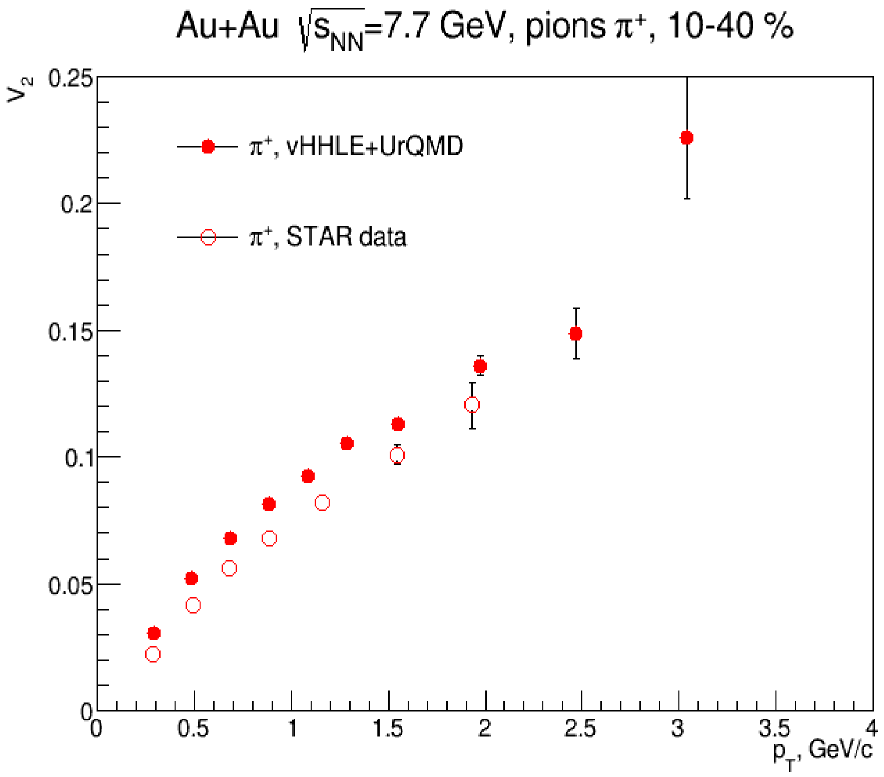
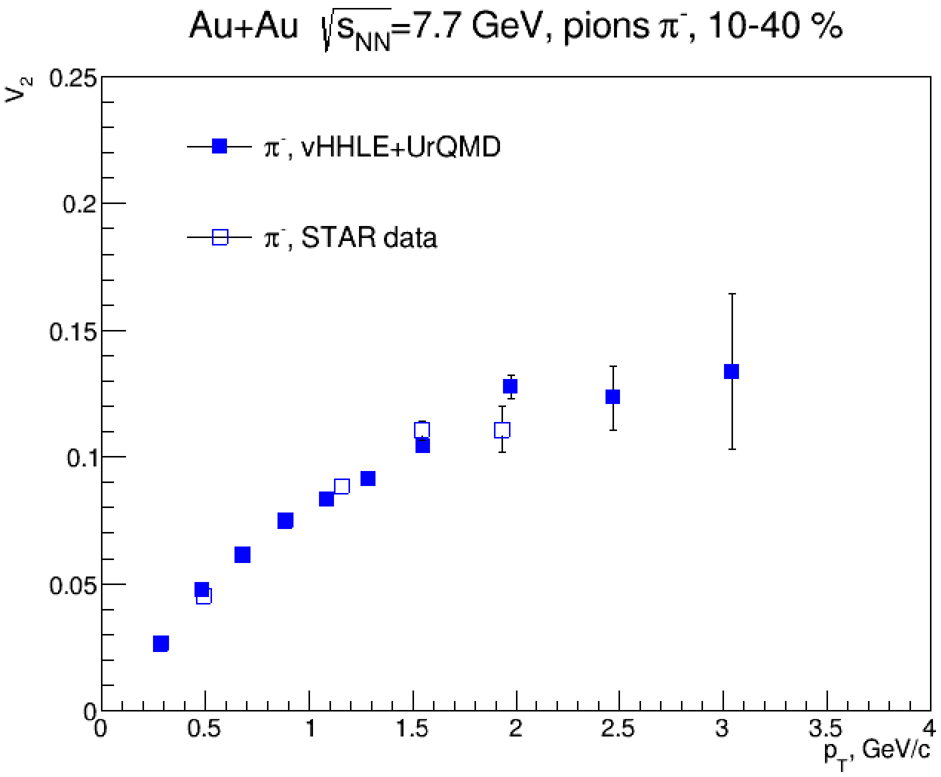


# Differential elliptic flow of pions: 3D hydro vHLLE + UrQMD

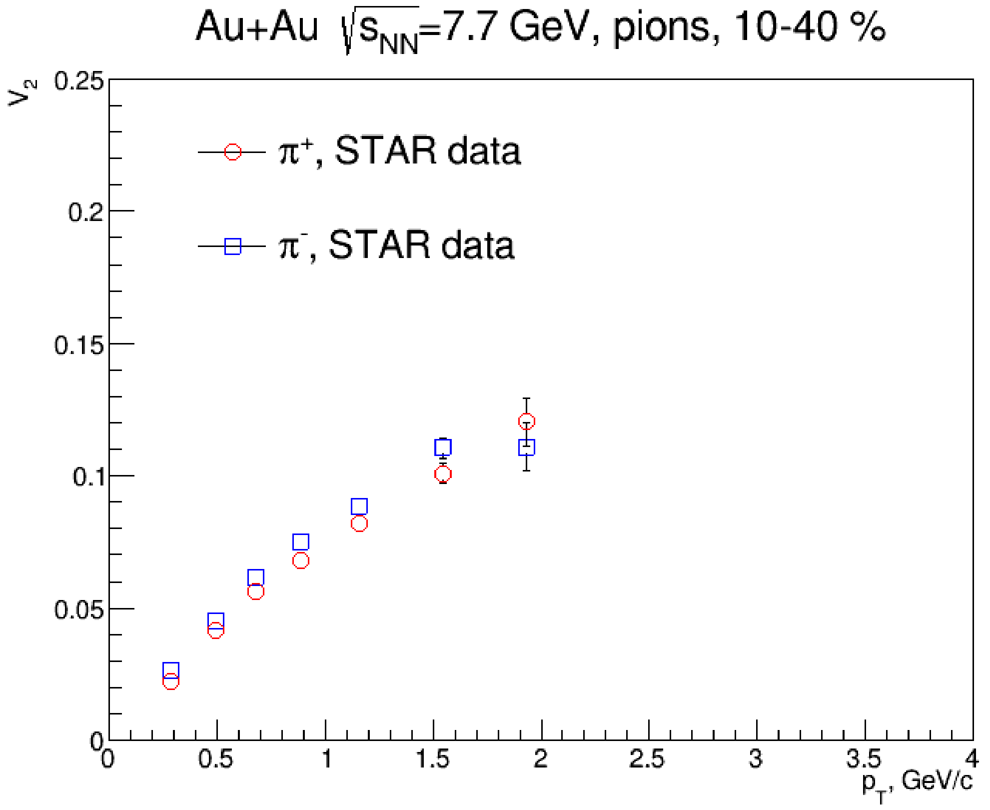


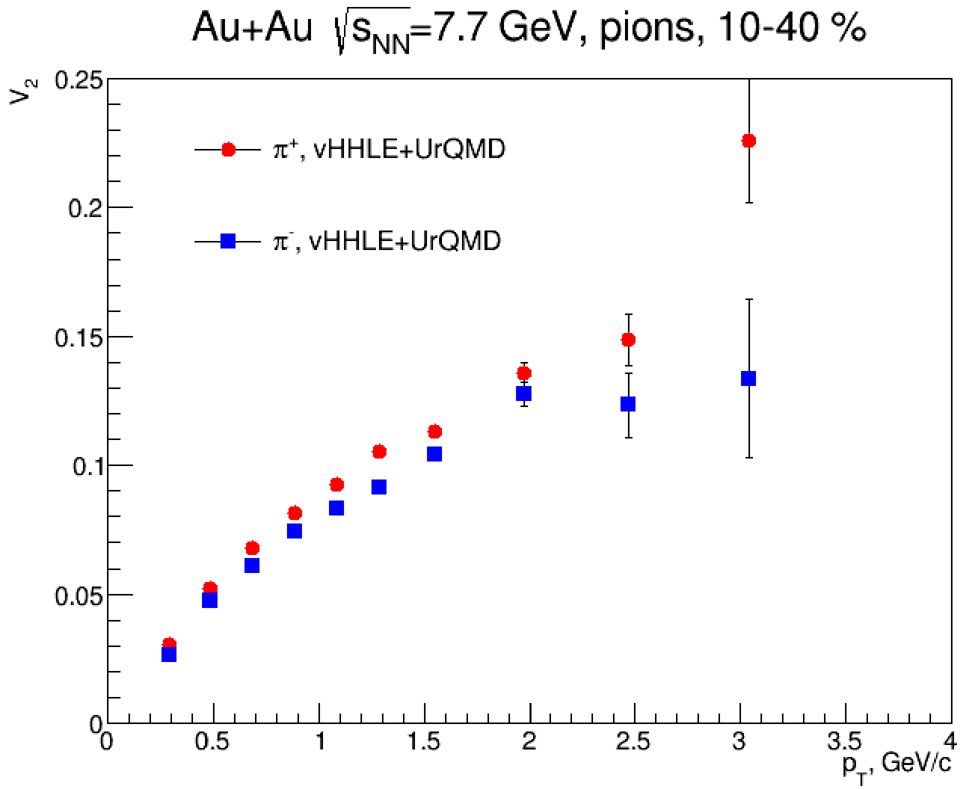




3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

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

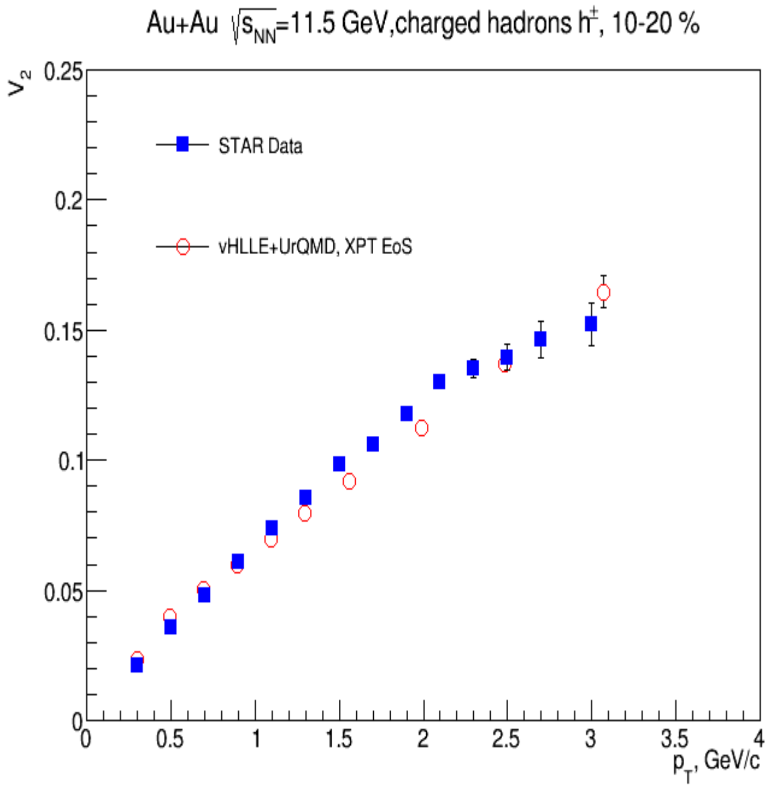
# Differential elliptic flow of pions: 3D hydro vHLLE + UrQMD

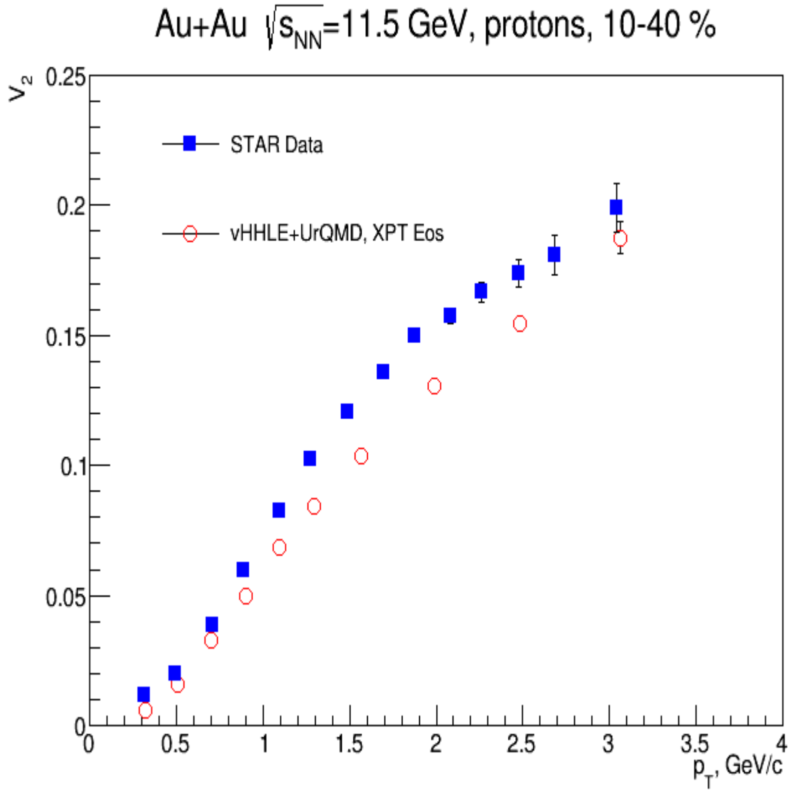



**At NICA energies the elliptic flow if different for particles and anti-particles!**

# Differential elliptic flow: 3D hydro vHLLE + UrQMD

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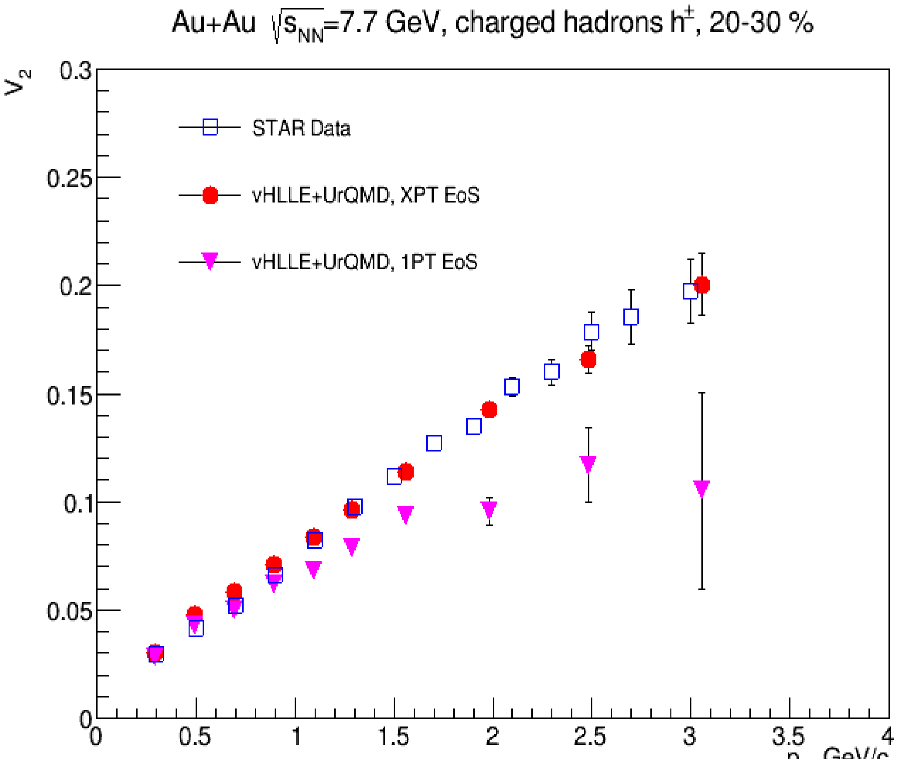
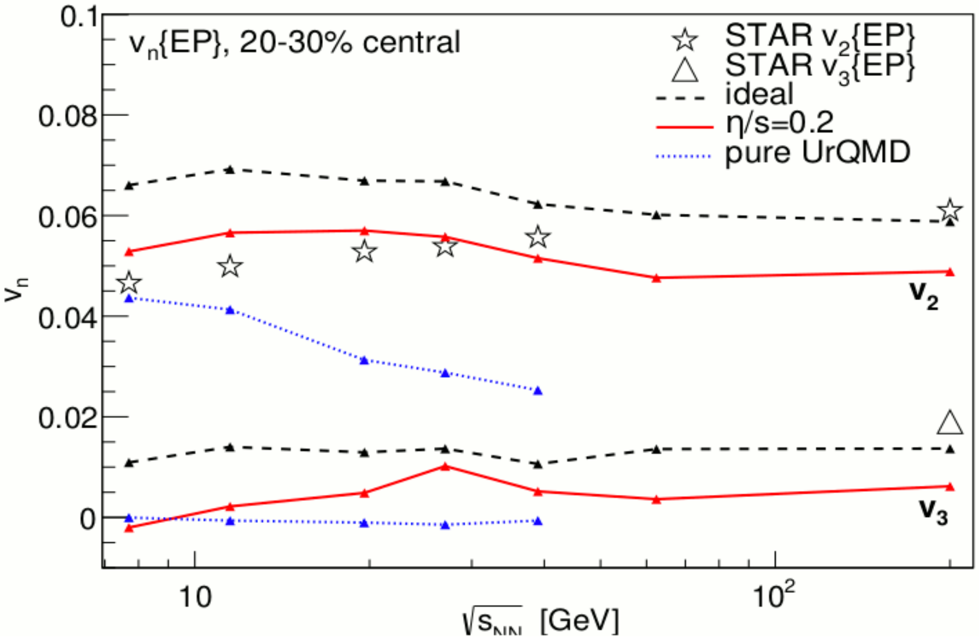
Reasonable agreement with STAR published data – need tuning ?

# 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

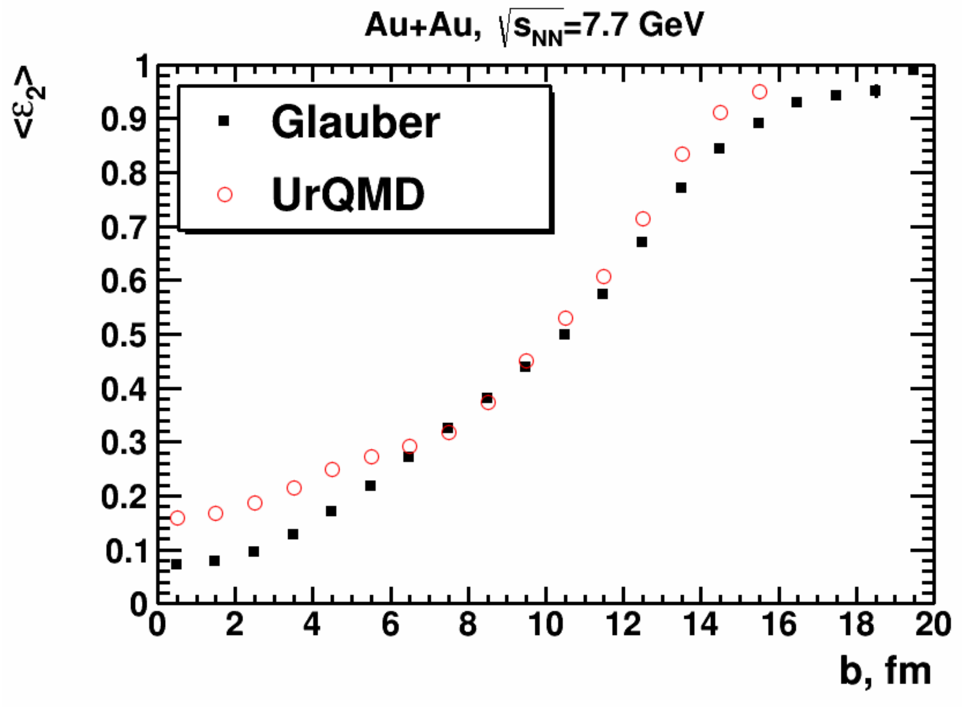


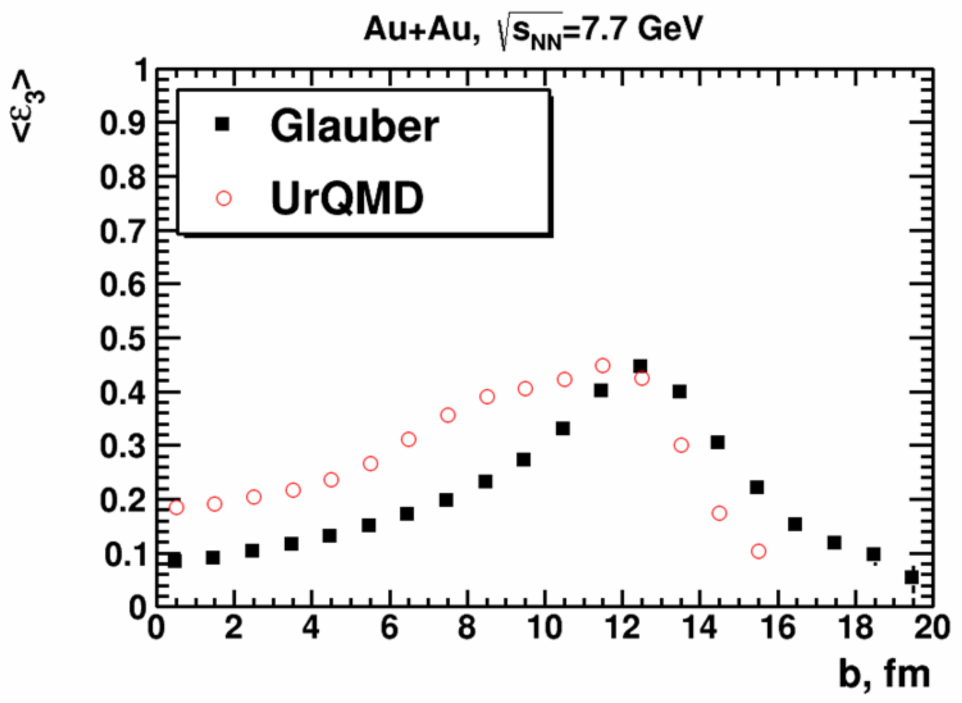

3D hydro model vHLLE + UrQMD (XPT EoS vs 1PT EoS) shows sensitivity of $v_2$ to the EoS

$v_3$=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

# Summary

**Anisotropic flow performance study in MPD (NICA):**

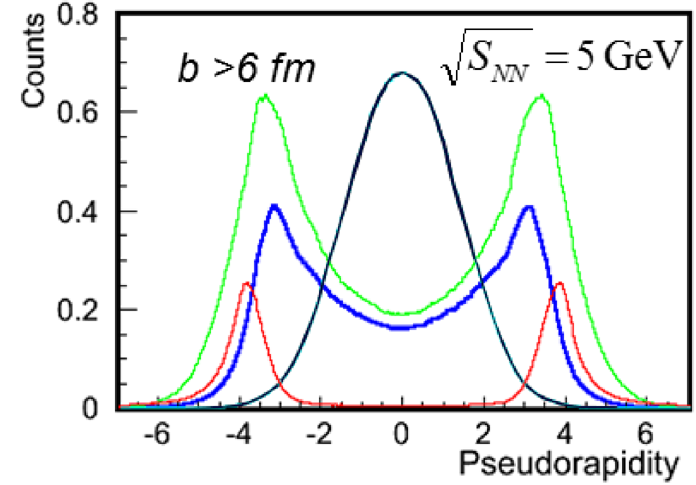
- Full reconstruction chain was implemented:
  - Combined particle identification based on TPC and TOF
  - Realistic hadronic simulation (GEANT4)
- Reconstructed $v_1$,$v_2$ are in agreement with MC generated data

- **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)

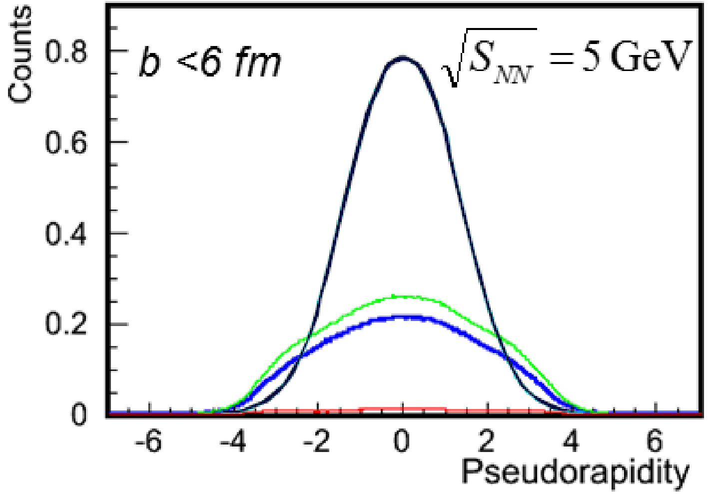
**Thank you for your attention!**

# Backup

# FHCal and TPC acceptance




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

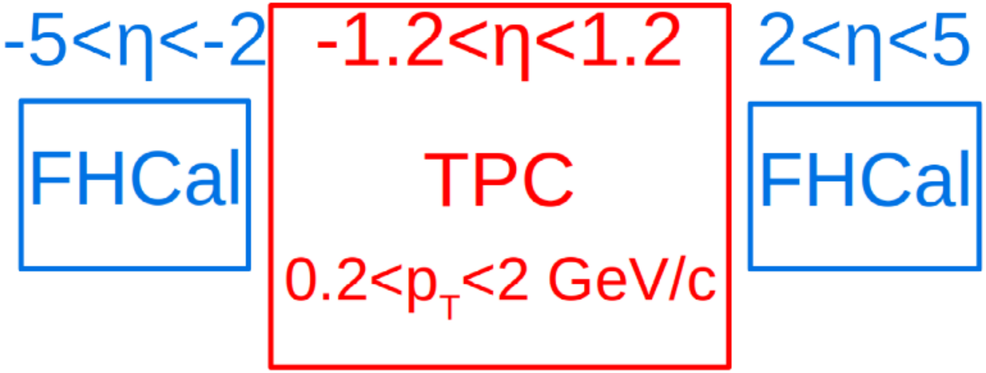



Pions

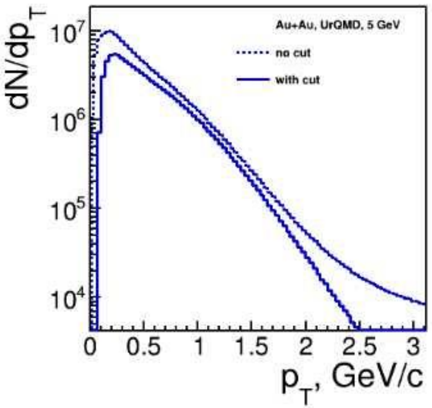
Neutrons

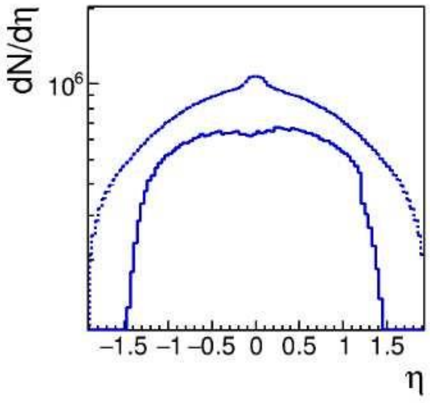
Protons

Fragments

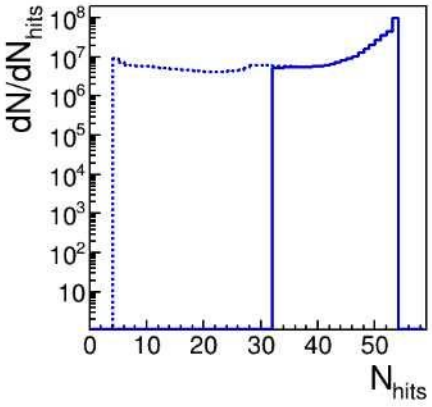


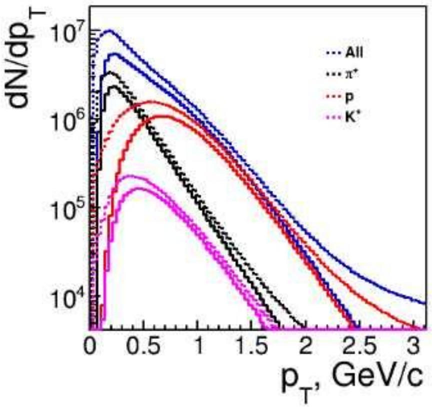
# Track selection

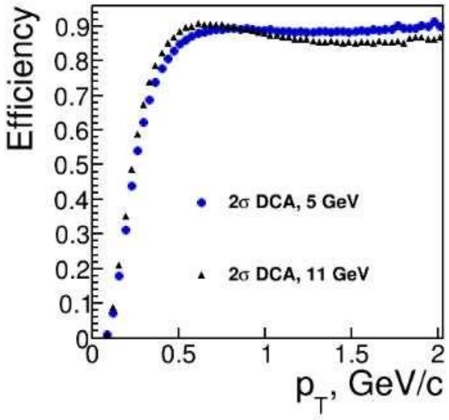


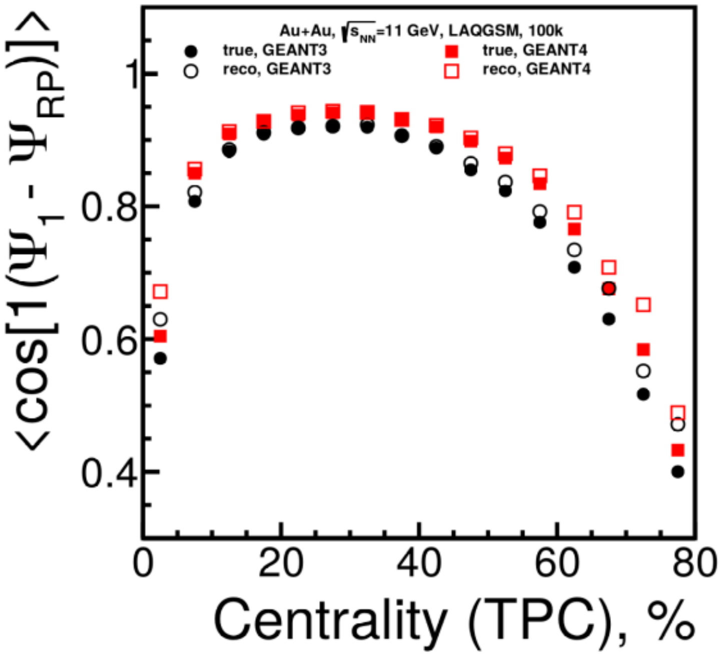

- $N_{TPC\ hits}$ >32
- $|p_T|$<3
- $|\eta|$<1.5
- PID based on TPC+TOF (MpdPid)

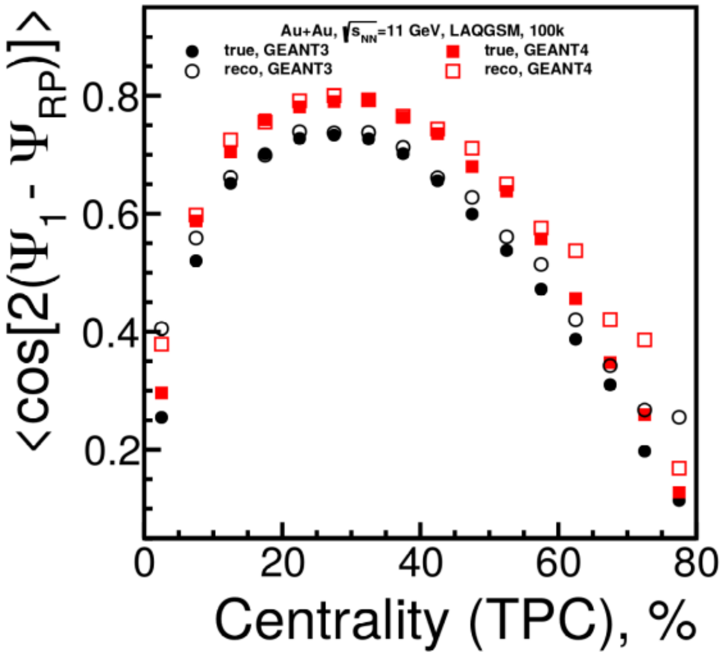


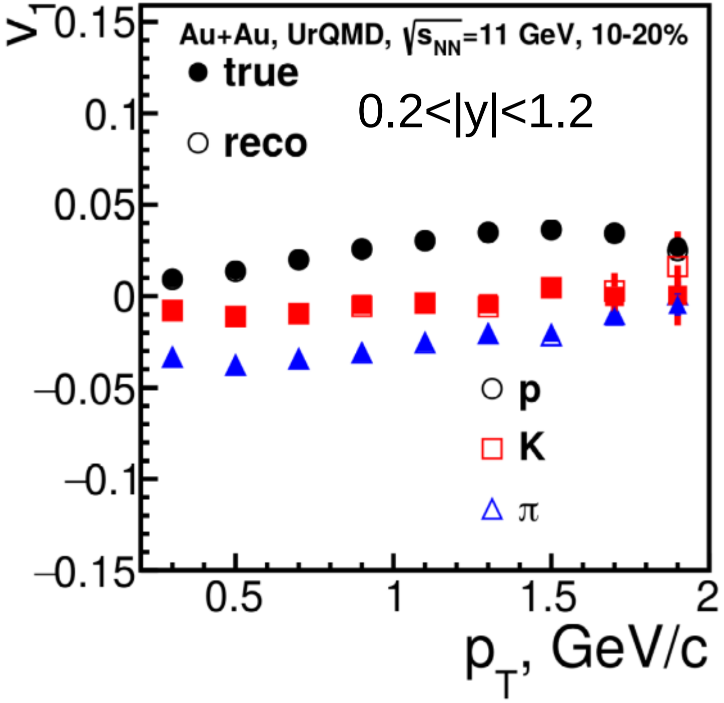
# Resolution correction factor: GEANT3 vs GEANT4 comparison

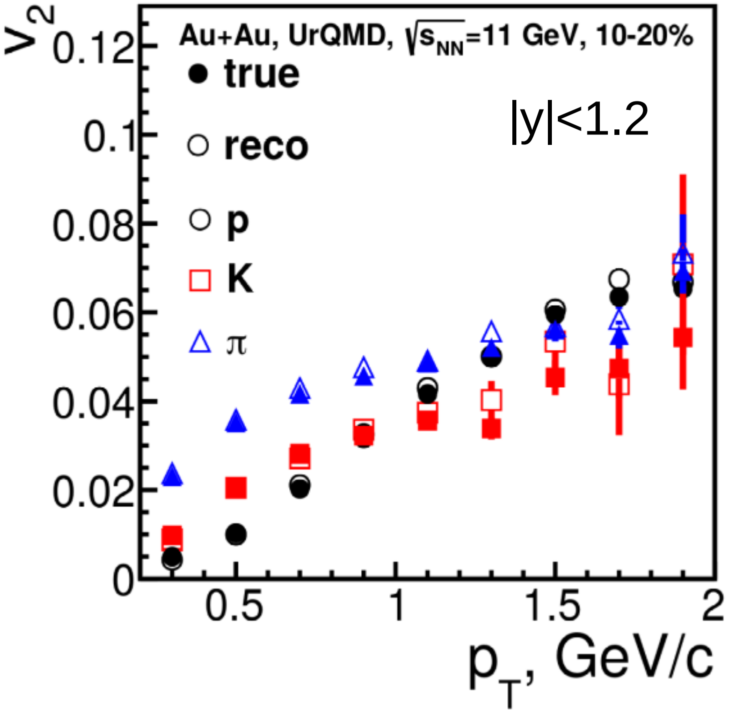



GEANT4 has more realistic hadronic shower simulation

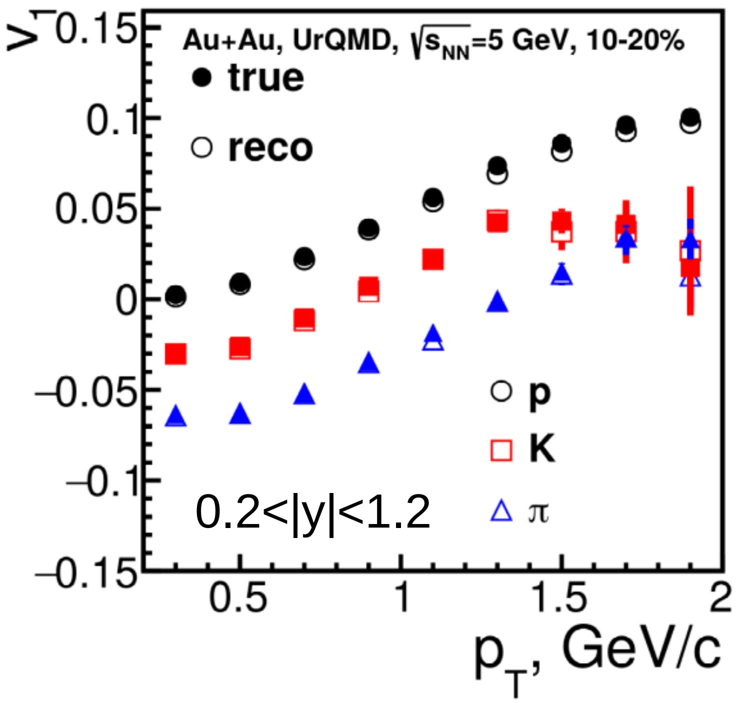
# $v_{1,2}\,(p_T)$, Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

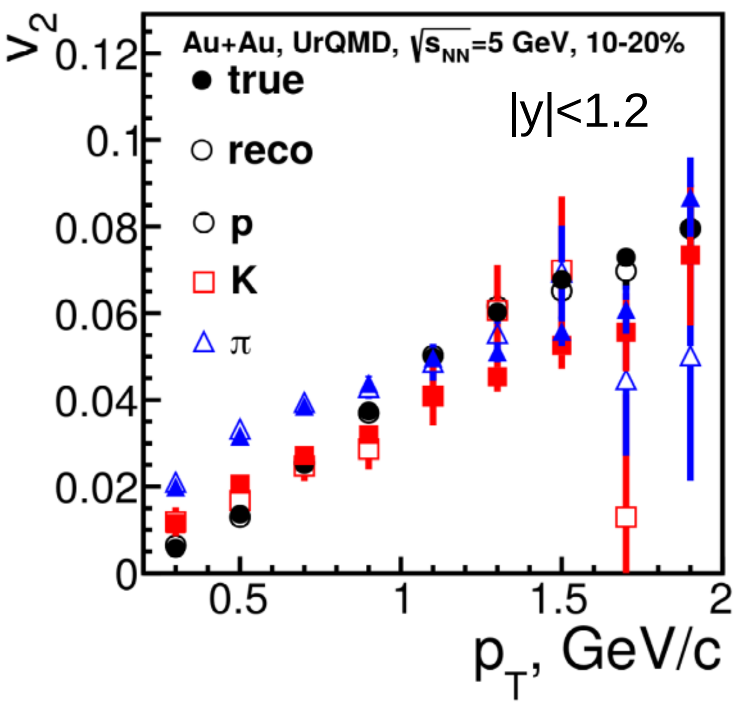



nd elliptic flow results after reconstruction and resolution correction are consistent to that o

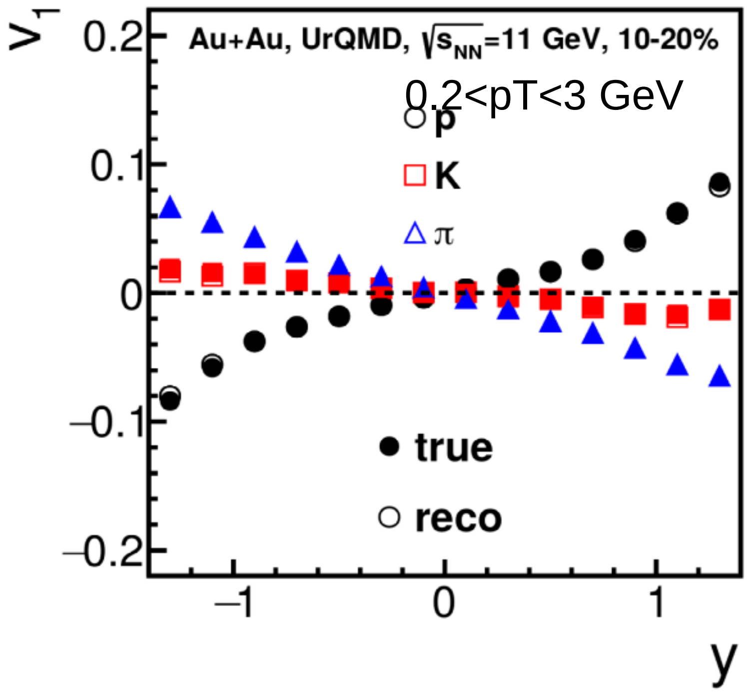
# $v_{1,2}$ ($p_T$), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV

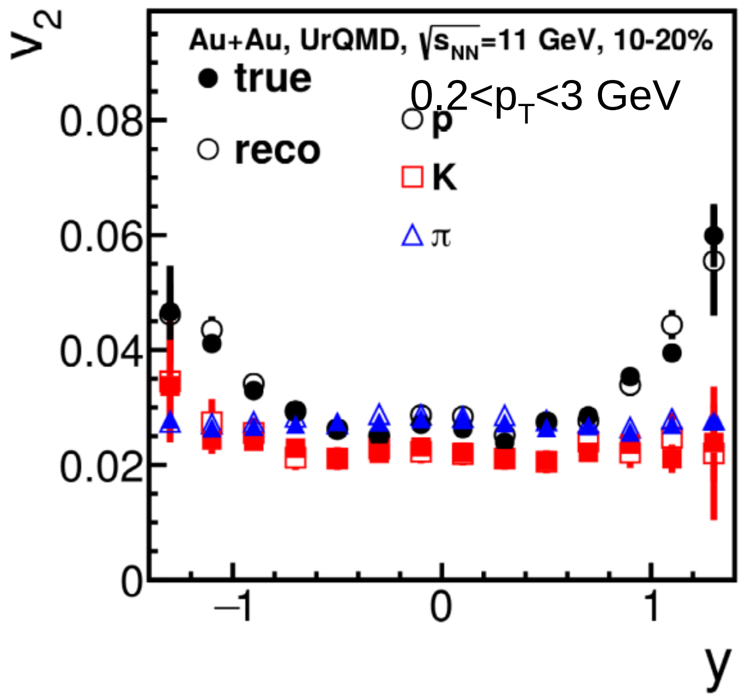



nd elliptic flow results after reconstruction and resolution correction are consistent to that o

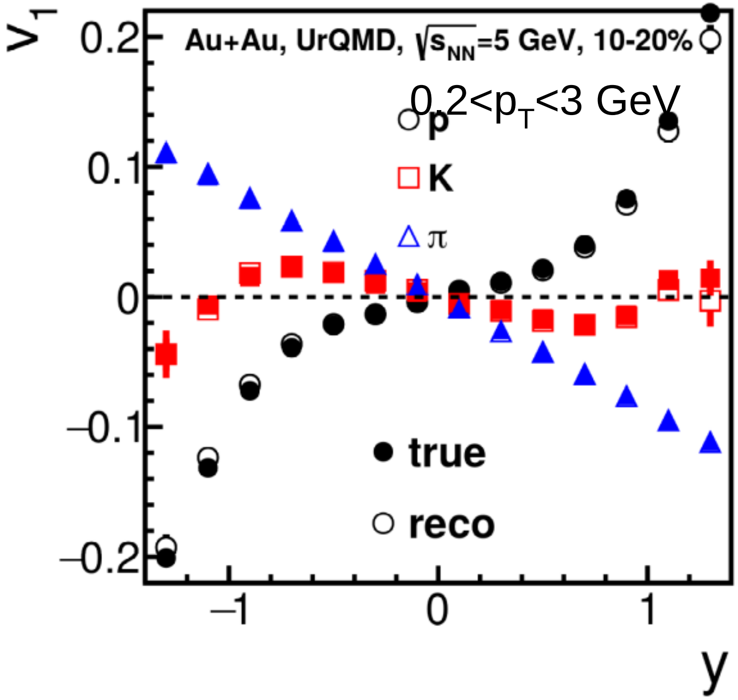
# $v_{1,2}$ (y), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

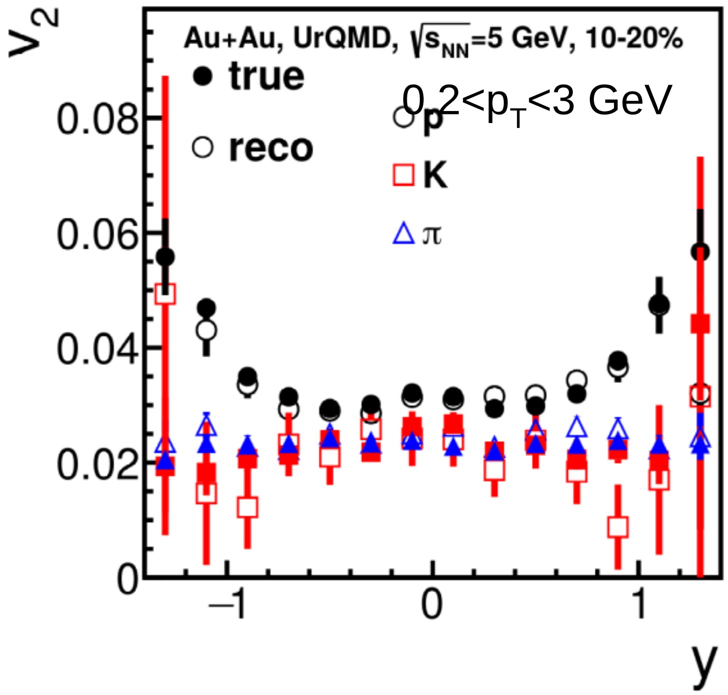



nd elliptic flow results after reconstruction and resolution correction are consistent to that o

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




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