Identified charged hadron flow in MPD at NICA

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for the MPD Collaboration

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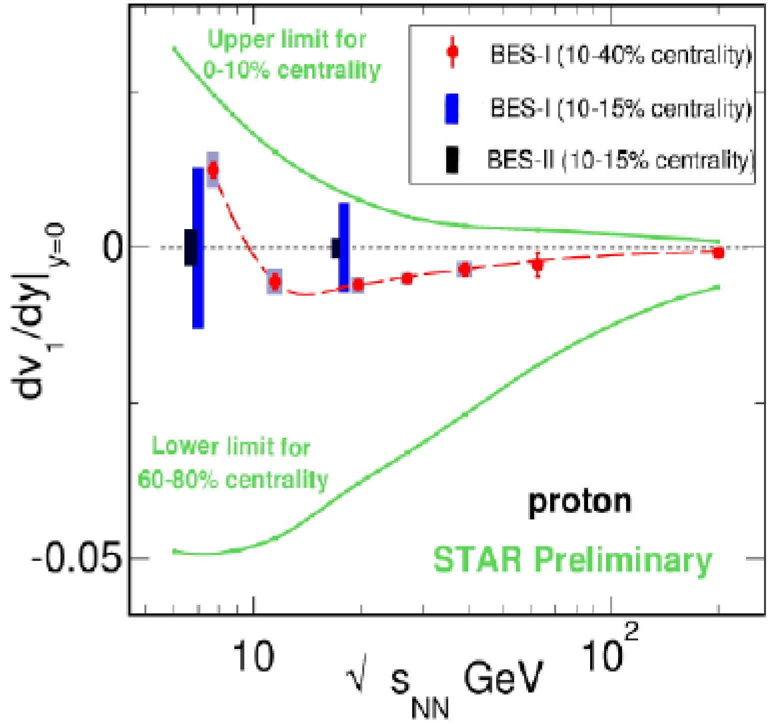
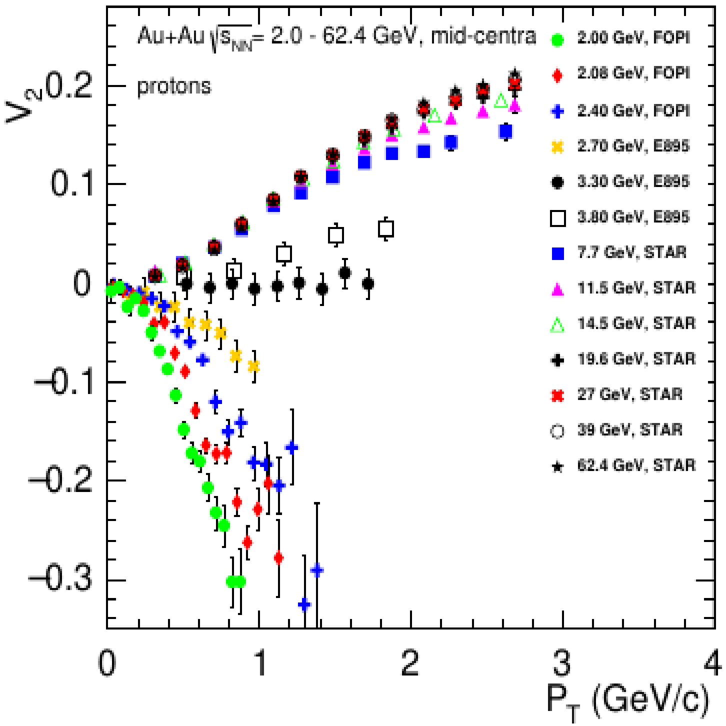
Outline

- Introduction
- Flow performance in MPD
  - Test of corrections for non-uniform acceptance
  - Methods comparison
  - Beam-energy dependence
  - Au+Au vs. Bi+Bi
  - TPC EP vs. FHCal EP
- Summary and outlook

Anisotropic flow at NICA energies

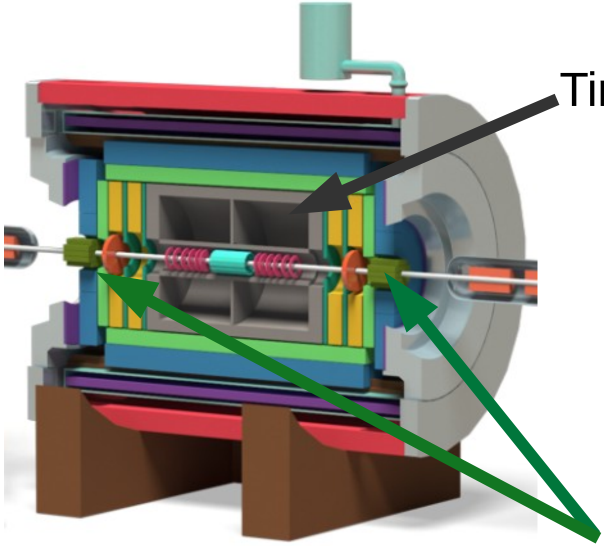




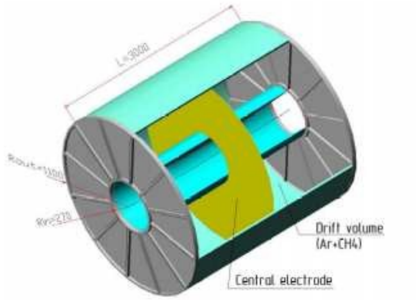
Anisotropic flow at NICA energies is a delicate balance between:
(i) the ability of pressure developed early in the reaction zone and
(ii) the passage time for removal of the shadowing by spectators

Flow performance study at MPD (NICA)

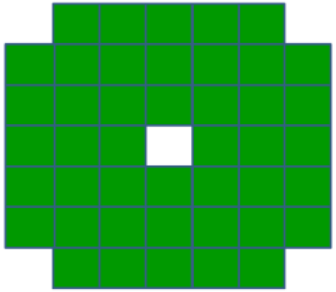
Multi Purpose Detector (MPD)



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

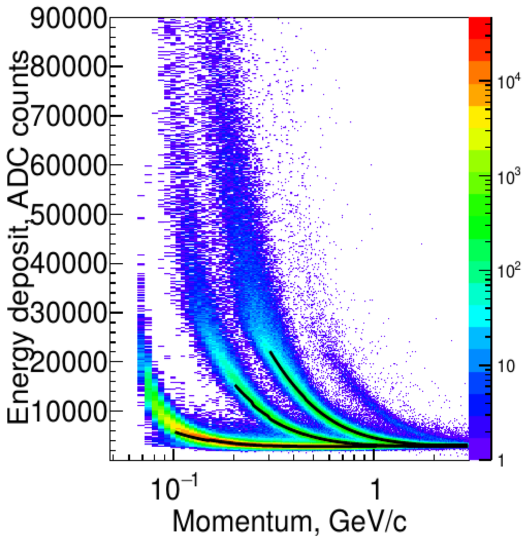
UrQMD
LAQGSM → GEANT4 → Reconstruction → Flow analysis

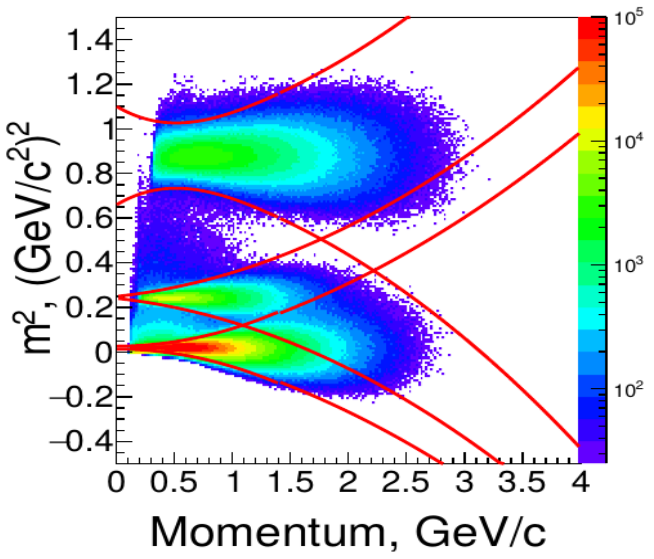
- Au+Au, N_{events} = 8 M events at $\sqrt{s_{NN}}$ = 4.5, 7.7 and 11 GeV
- Bi+Bi, N_{events} = 8 M events at $\sqrt{s_{NN}}$ = 7.7 GeV

- TPC
- FHCal
- TOF
- ...

Event classification:
- Track multiplicity
- FHCal energy

Track selection:
- Primary tracks (2σ DCA cut)
- $N_{TPC\ hits} > 32$
- $0.2 < p_T < 3$ GeV/c
- $|\eta| < 1.5$
- PID based on TPC+TOF (MpdPid)





MPDRoot, December 2019

Event plane method implementation in MPD (NICA)

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

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

FHCal EP: $m=1,\ \omega=E$

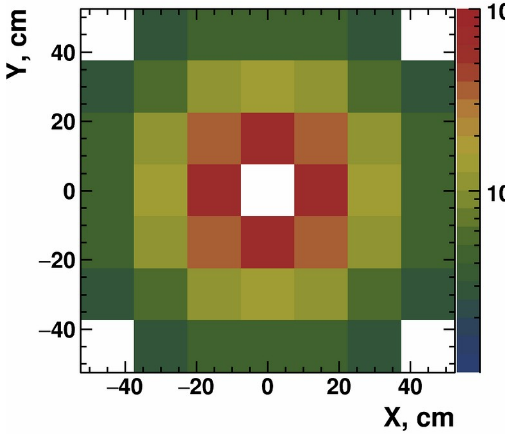
TPC EP: $m=2,\ \omega=p_T$

- Both FHCal detecors were used for EP
- *E* is the energy deposition in FHCal module
- p_T is the track's transverse momentum in TPC
- φ_i is its azimuthal angle
- For *m=1* weights had different signs for backward and forward rapidity
- Δη-gap>0.05 between TPC sub-events (TPC EP)
- Δη-gap>0.5 between TPC and FHCal (FHCal EP)

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

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

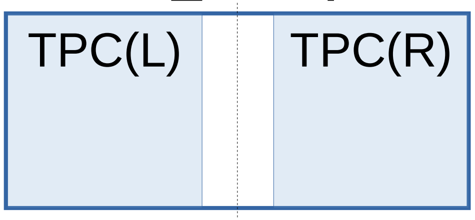
$$v_n = \frac{\langle \cos[n(\Psi_{RP} - \Psi_m^{EP})] \rangle}{Res_n\{\Psi_m^{EP,true}\}}$$



Energy distribution in FHCal

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

$v_2(p_T)$: EP vs. SP methods



-1.5 < η < -0.05 0.05 < η < 1.5

Left TPC half $(\eta < -0.05) \rightarrow \eta_-$

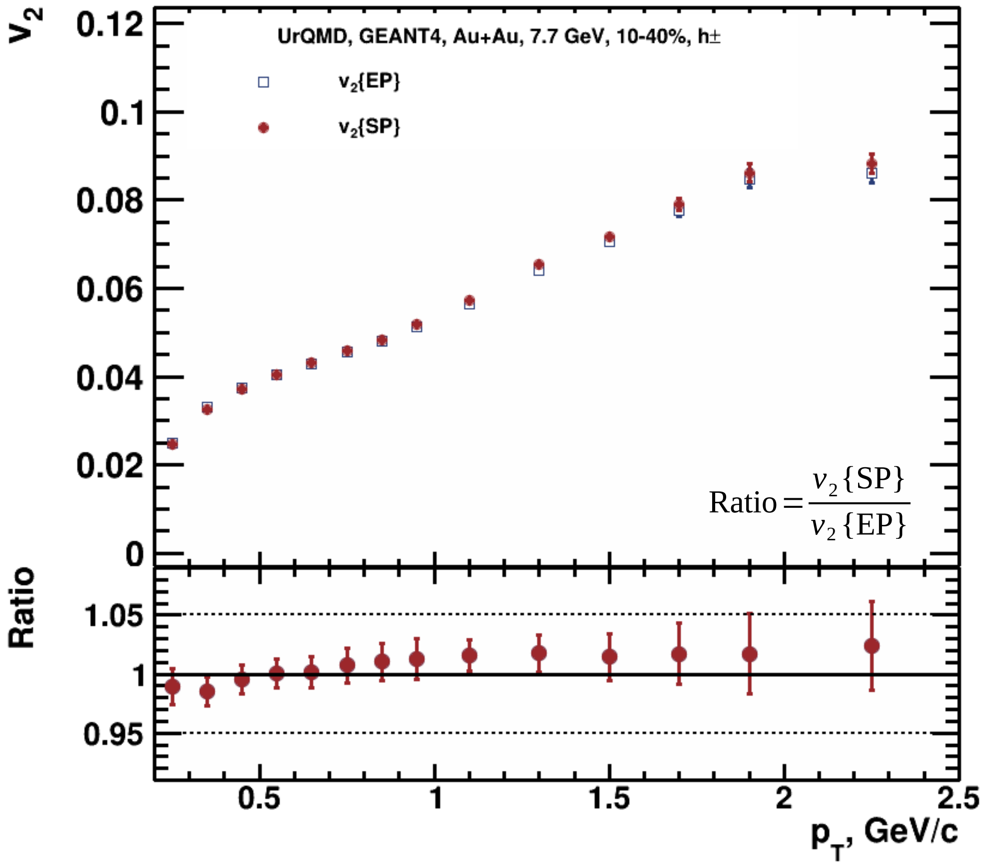
Right TPC half $(\eta > 0.05) \rightarrow \eta_+$

Event Plane (EP):

$$v_2\{EP\} = \frac{\left\langle \cos\left[2\left(\varphi_{\eta\pm} - \Psi_{2,\eta\mp}\right)\right]\right\rangle}{\sqrt{\left\langle \cos\left[2\left(\Psi_{2,\eta+} - \Psi_{2,\eta-}\right)\right]\right\rangle}}$$

Scalar Product (SP):

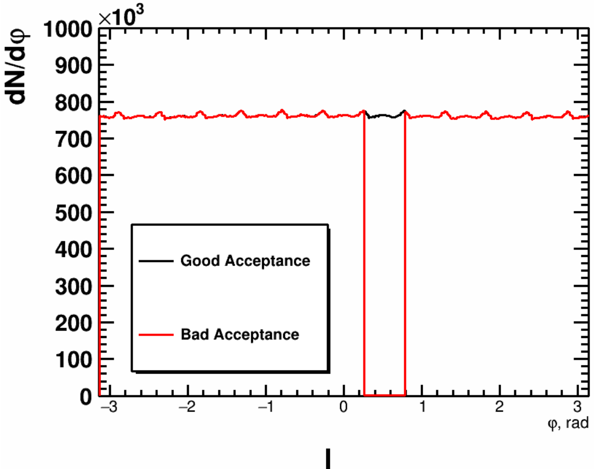
$$v_2\{SP\} = \frac{\left\langle u_{2,\eta\pm} Q^*_{2,\eta\mp}\right\rangle}{\sqrt{\left\langle Q_{2,\eta-} Q^*_{2,\eta+}\right\rangle}}, \quad u_2 = e^{i(2\varphi)}, \quad Q_2 = \sum_k^{k_{\text{tracks}}} u_{2,k}$$

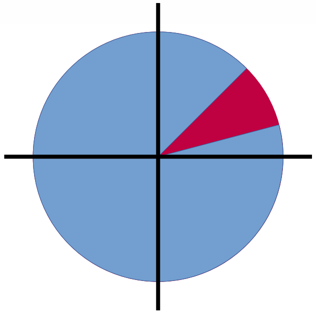


Good agreement between Event Plane and Scalar Product methods

Acceptance filter

TPC

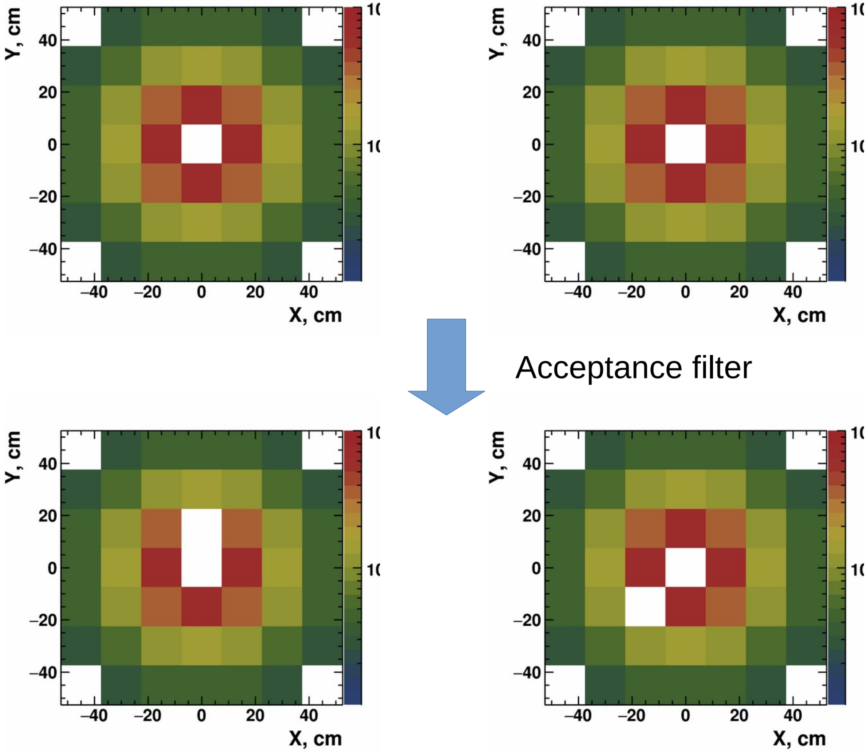




Area 15°< φ < 45° is off

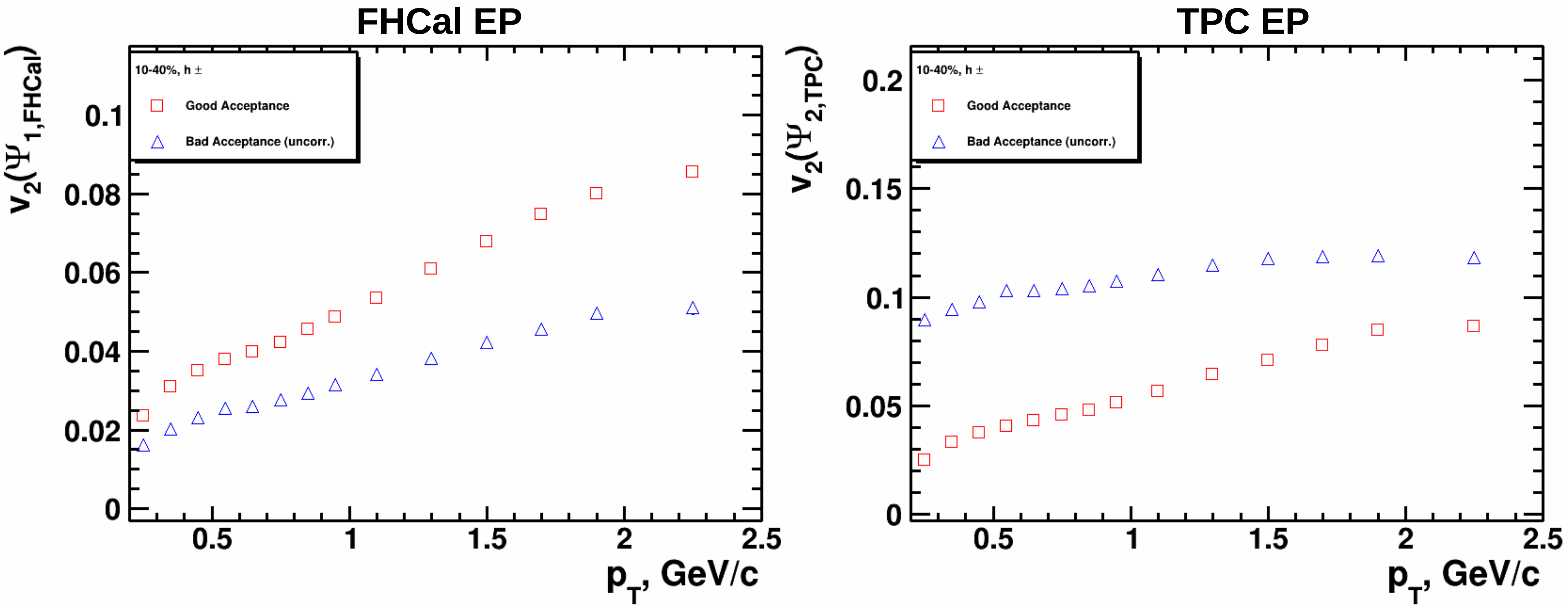
FHCal L

FHCal R



Modules 15 (L) and 28 (R) are off

$v_2(p_T)$: contribution from non-uniform acceptance

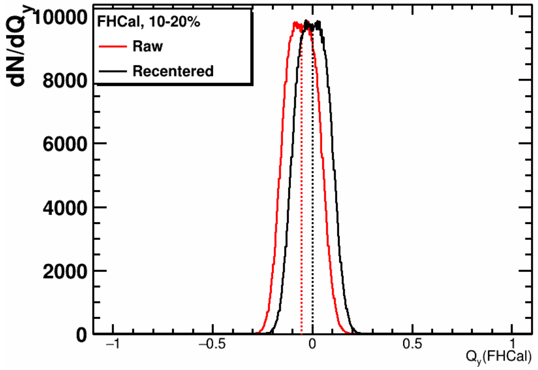


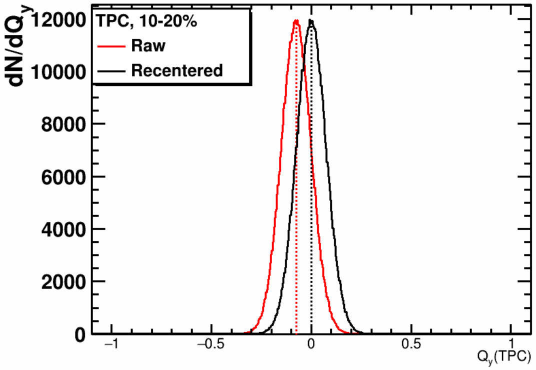
Corrections for non-uniform acceptance are needed

Corrections for non-uniform acceptance

- Recentering:

$$\vec{Q}_n = \vec{Q}_n^{\,\mathrm{Raw}} - \left\langle \vec{Q}_n^{\,\mathrm{Raw}} \right\rangle$$

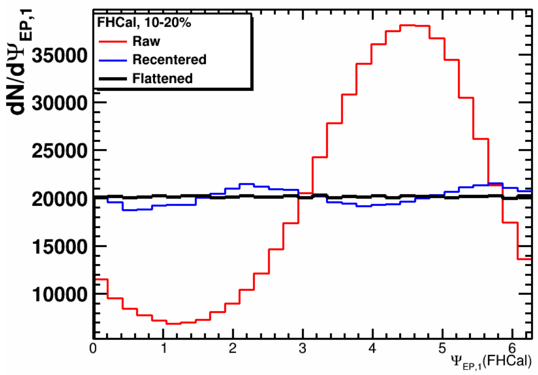


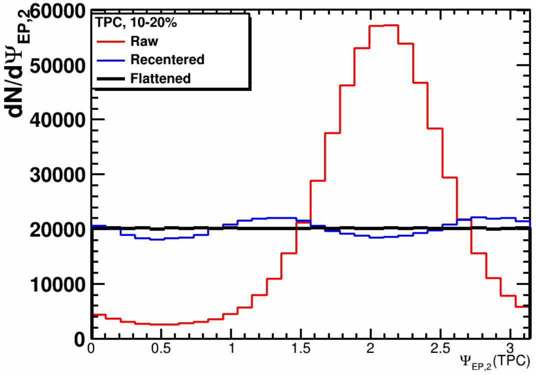


- Flattening:

$$\Psi_n = \Psi_n^{\mathrm{Recentered}} + \Delta\Psi_n$$

$$n\Delta\Psi_n = \sum_{i=1}^{i_{max}} \frac{2}{i}\left[-\left\langle \sin(in\Psi_n)\right\rangle \cos(in\Psi_n) + \left\langle \cos(in\Psi_n)\right\rangle \sin(in\Psi_n)\right]$$

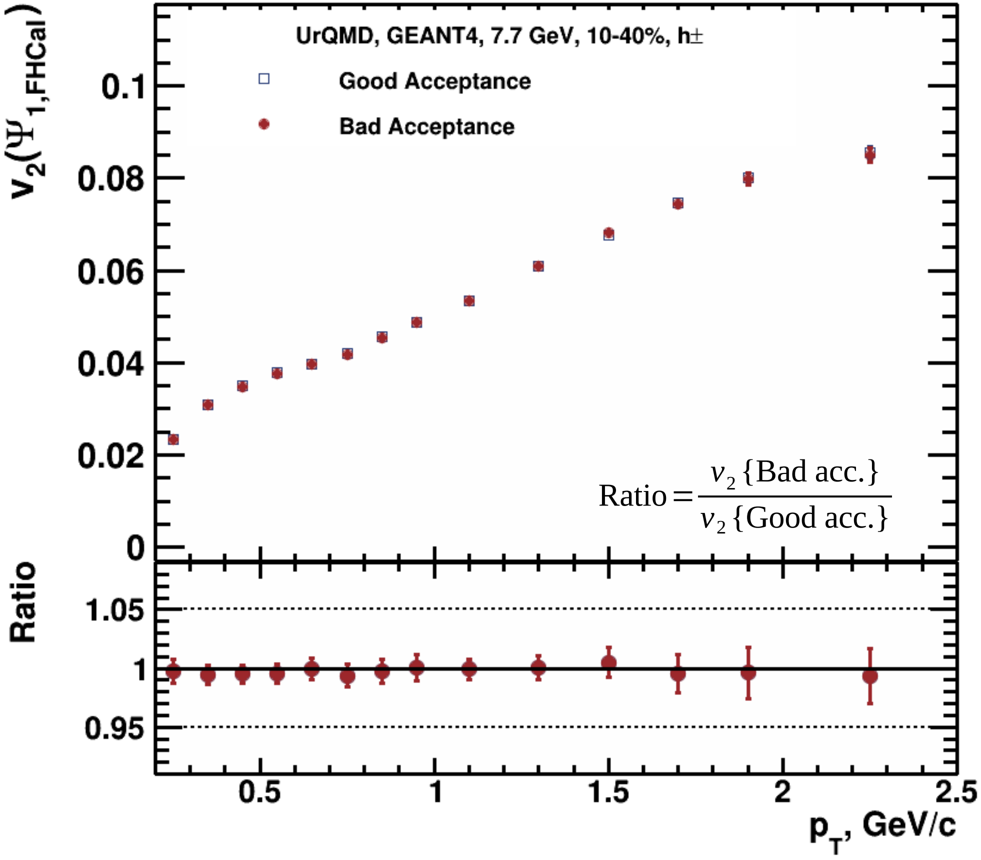




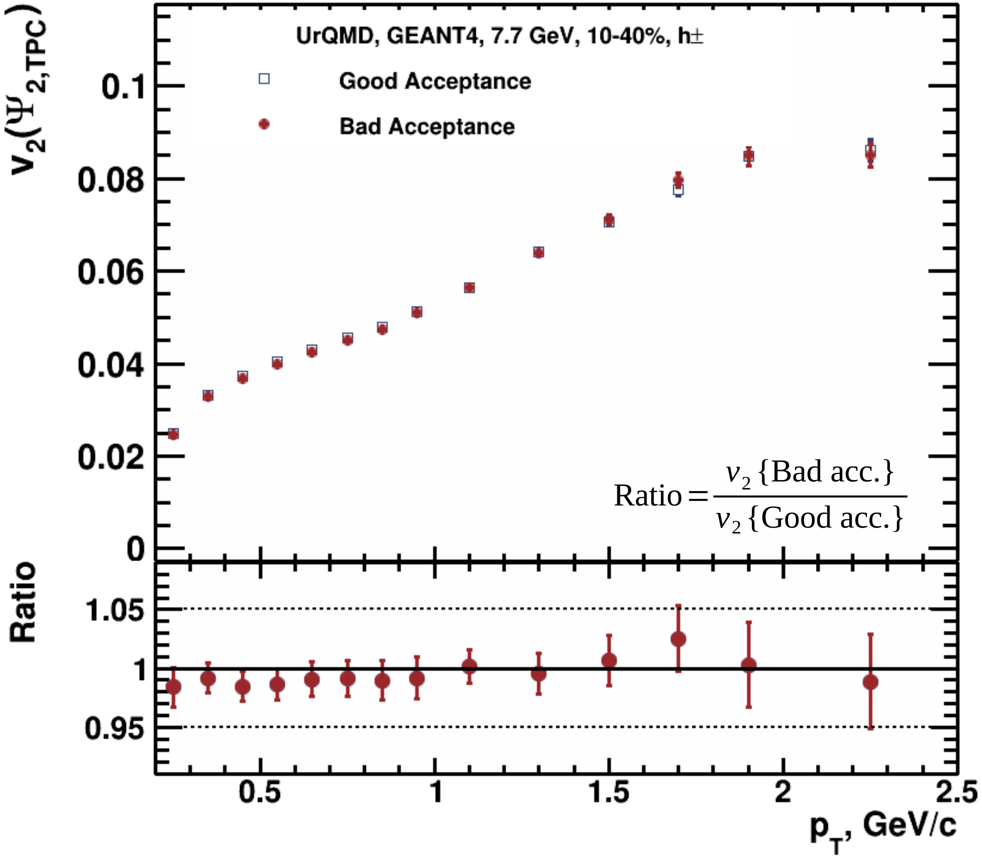
In this work n=1 (FHCal EP), n=2 (TPC EP), i_{max} = 12

$v_2(p_T)$: check of corrections

FHCal EP

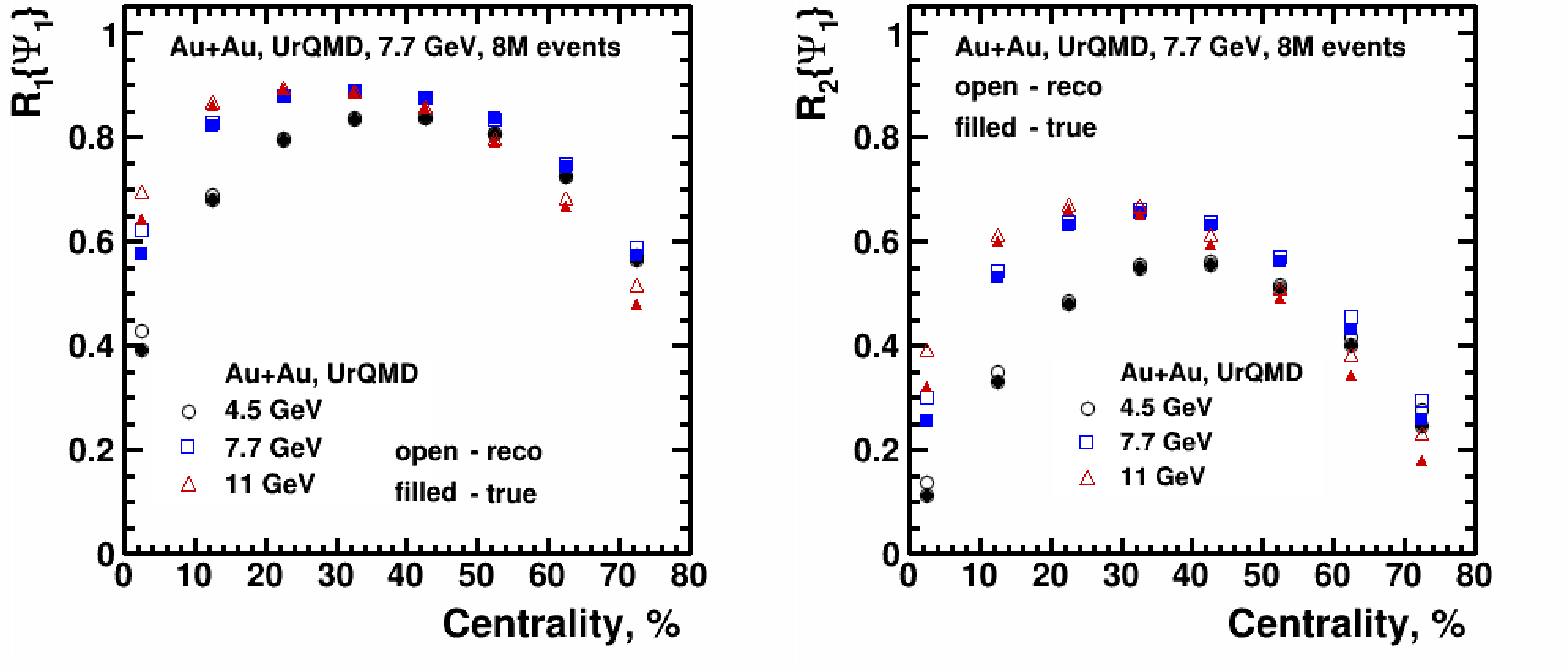


TPC EP



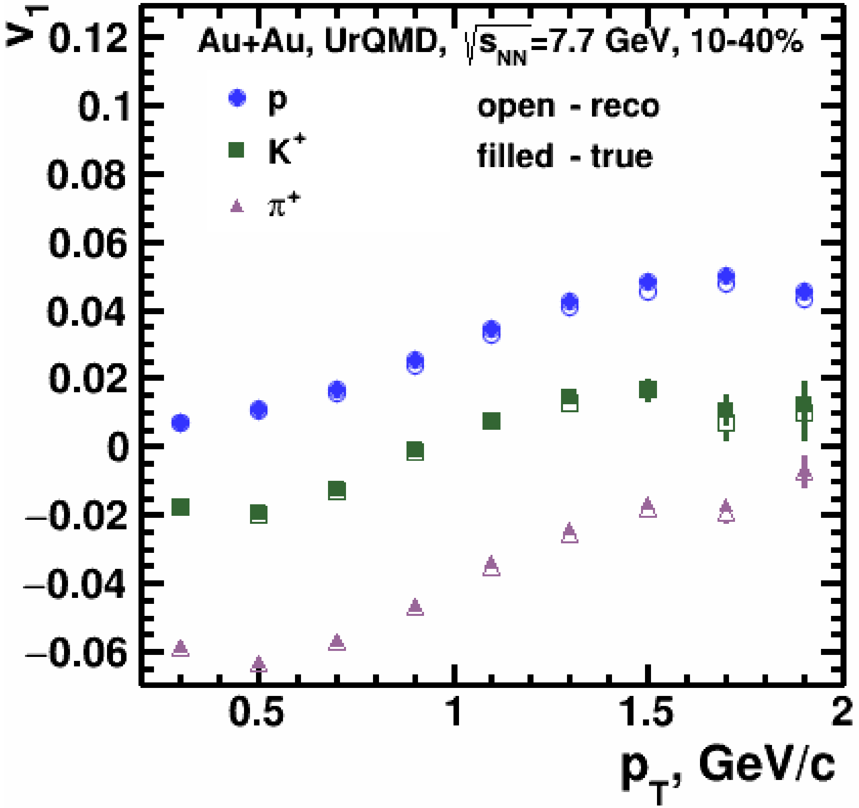
Good agreement with results for ideal (Good) acceptance

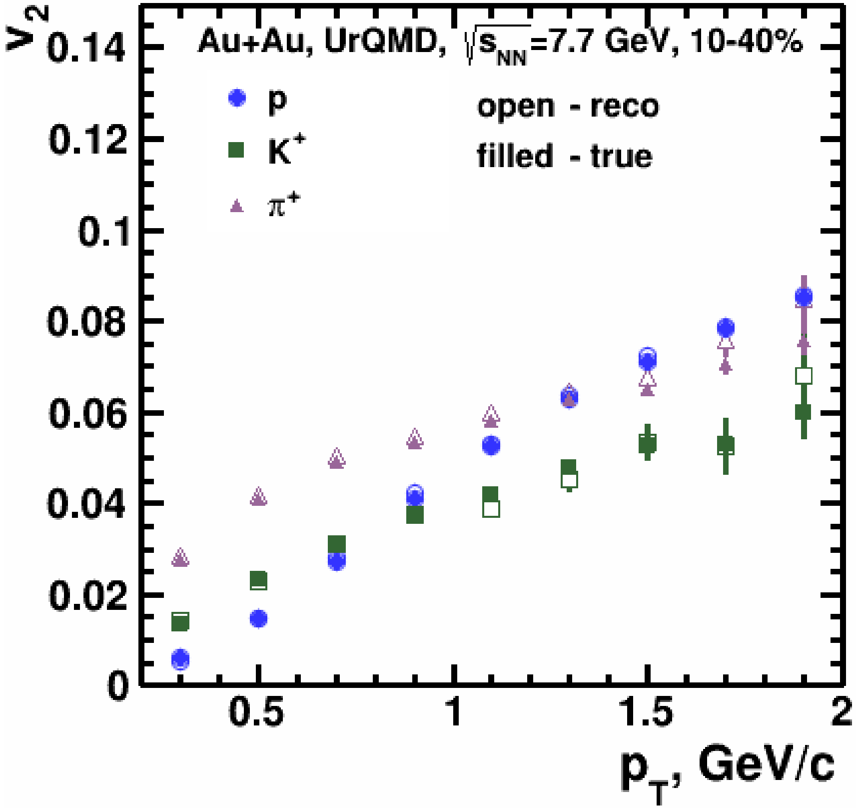
EP Resolution: energy dependence



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

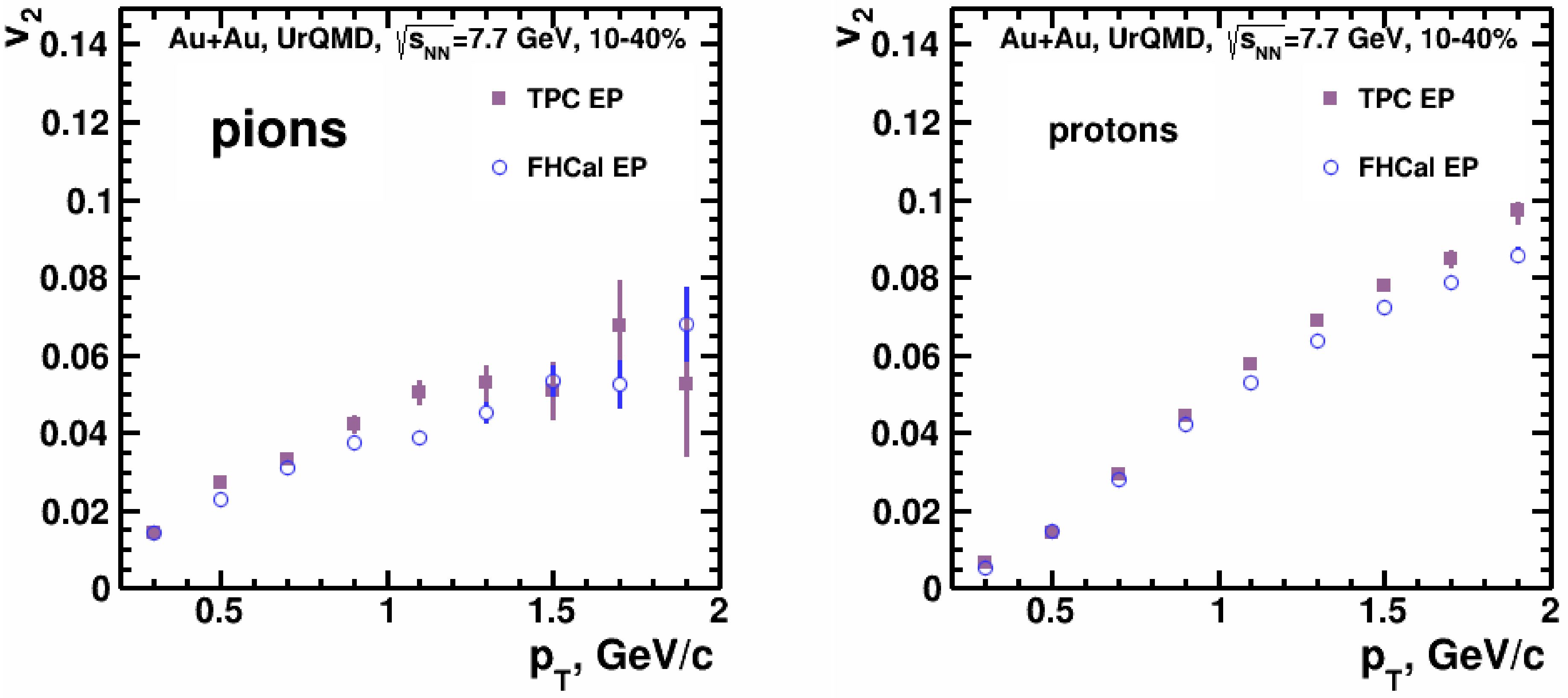
p_T-dependence of v_1 and v_2 of reconstructed signal





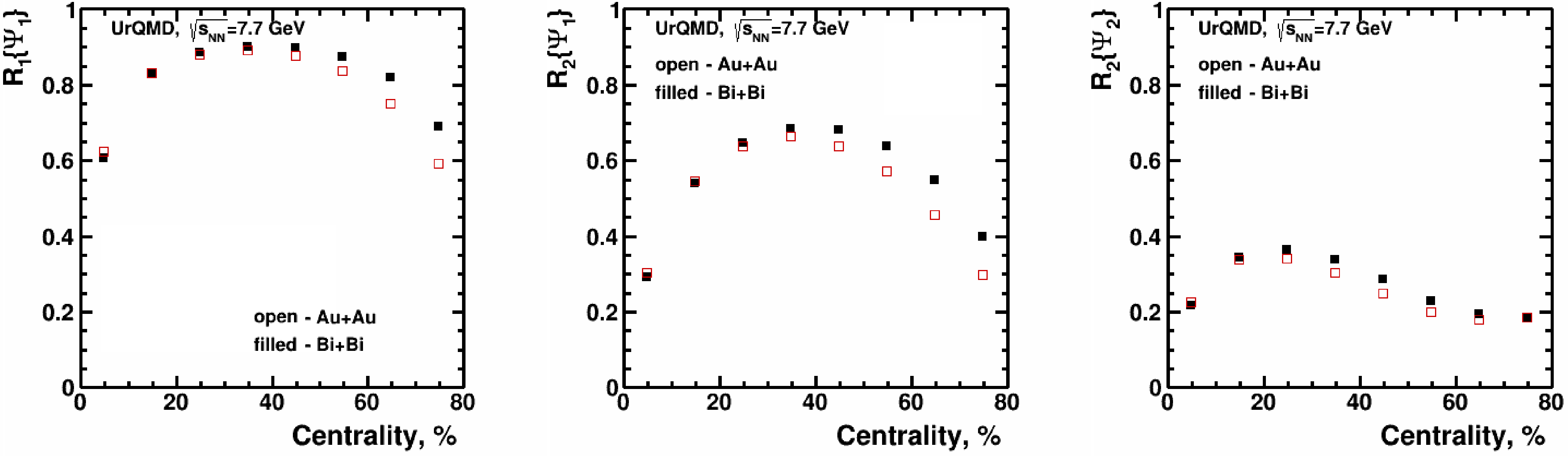
Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

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



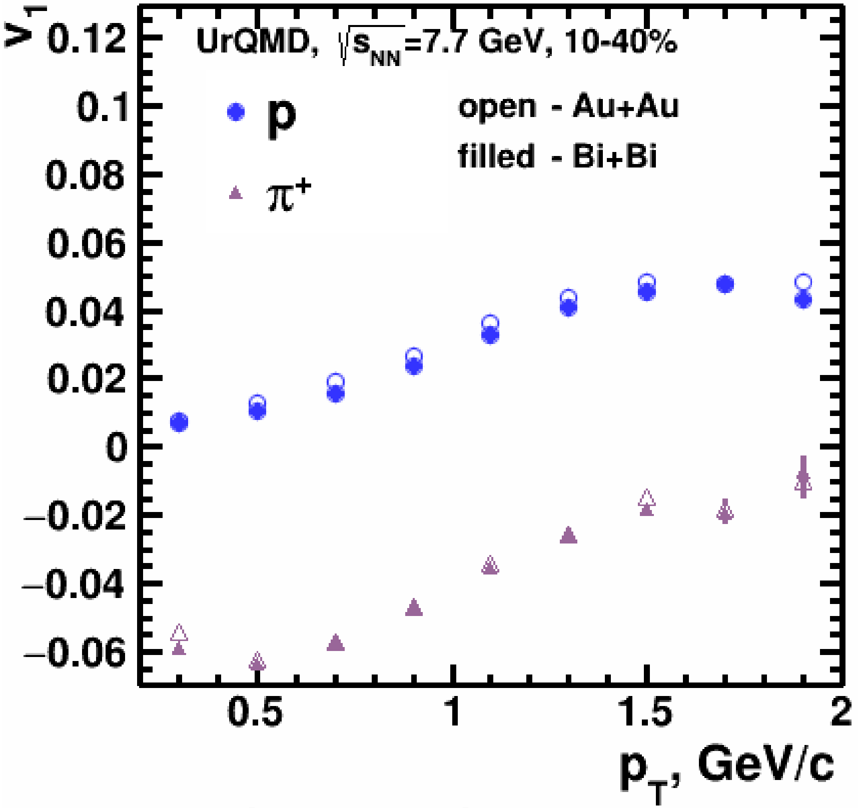
Expected small difference between v_2 measured with respect TPC ($\Psi_{2,EP}$) and FHCal ($\Psi_{1,EP}$)

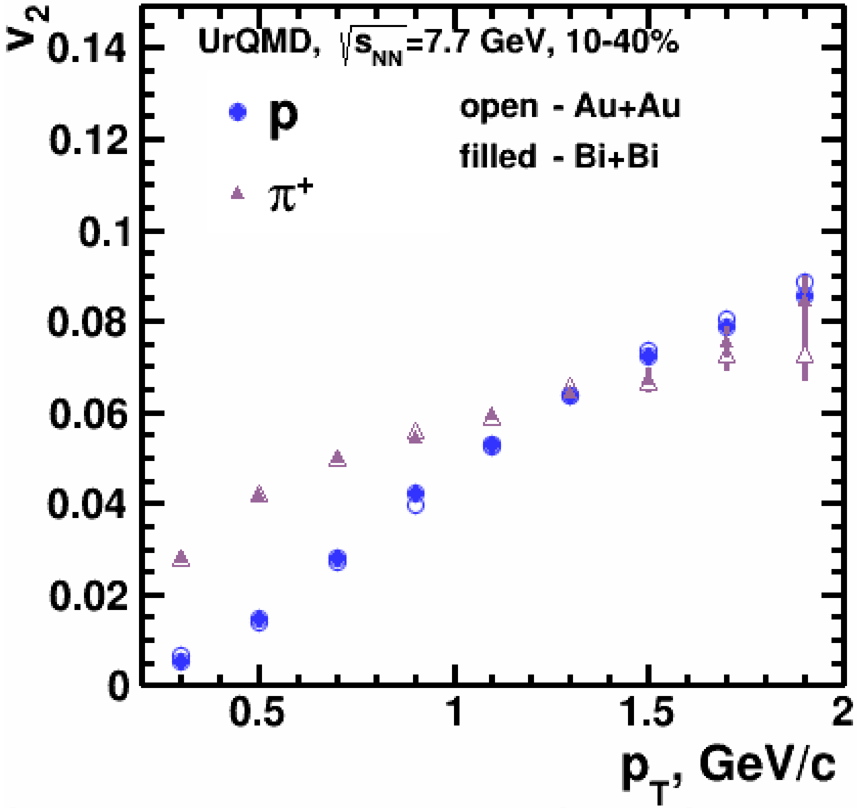
EP Resolution: Bi+Bi vs Au+Au



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

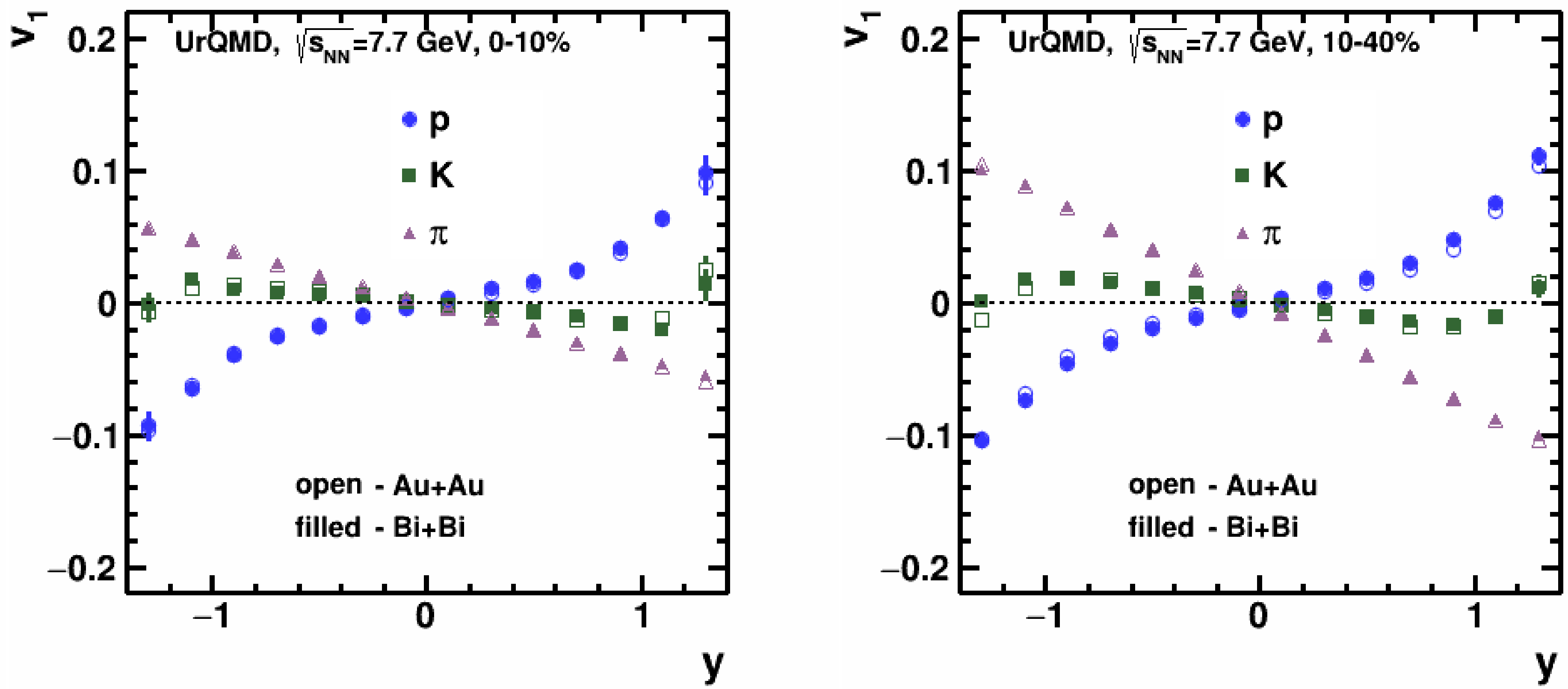
$v_n(p_T)$: Bi+Bi vs Au+Au





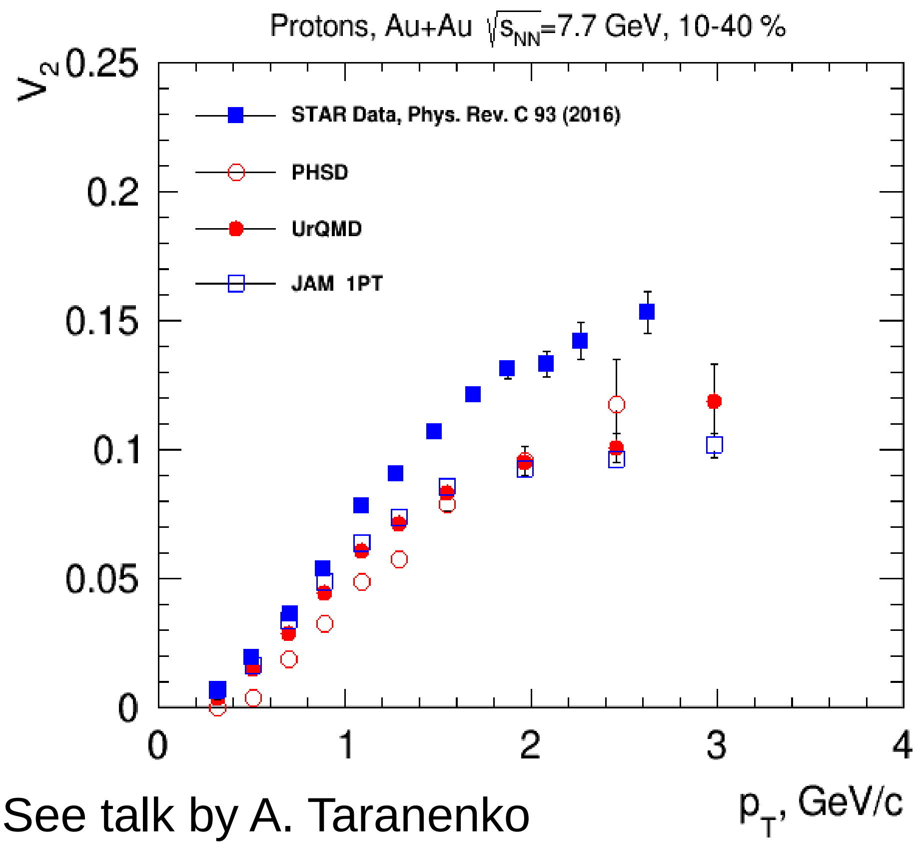
Expected small difference for v1 and v2 for particles produced in Au+Au and Bi+Bi collisions.

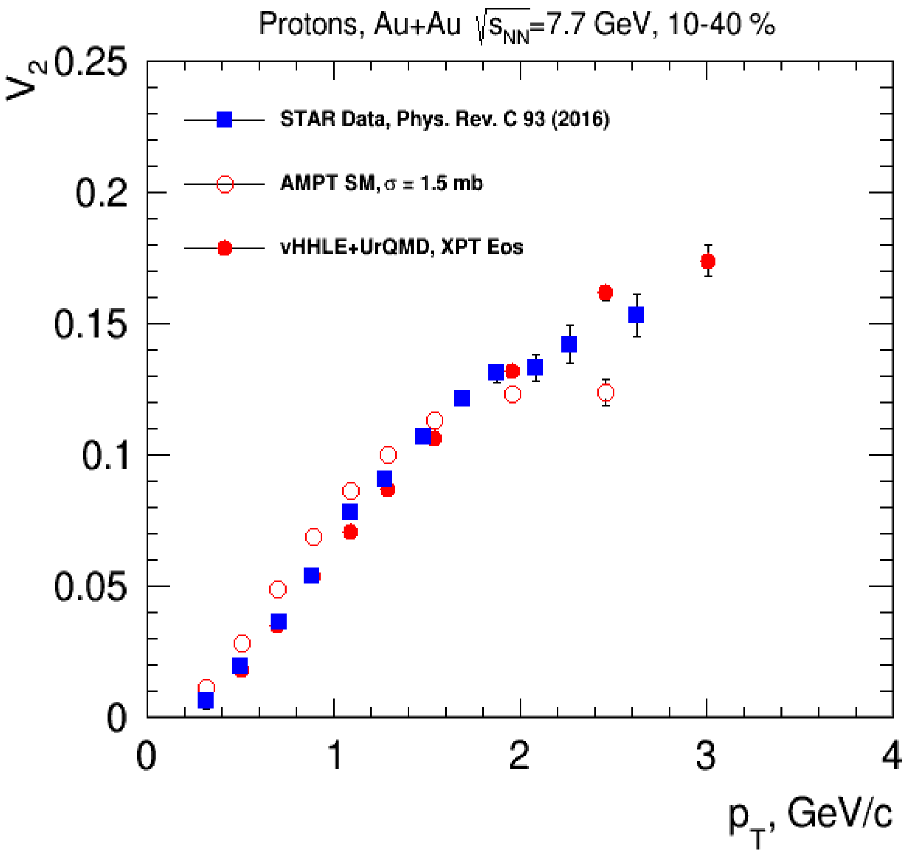
$v_1(y)$: Bi+Bi vs Au+Au



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

Elliptic flow: Models vs Data comparison

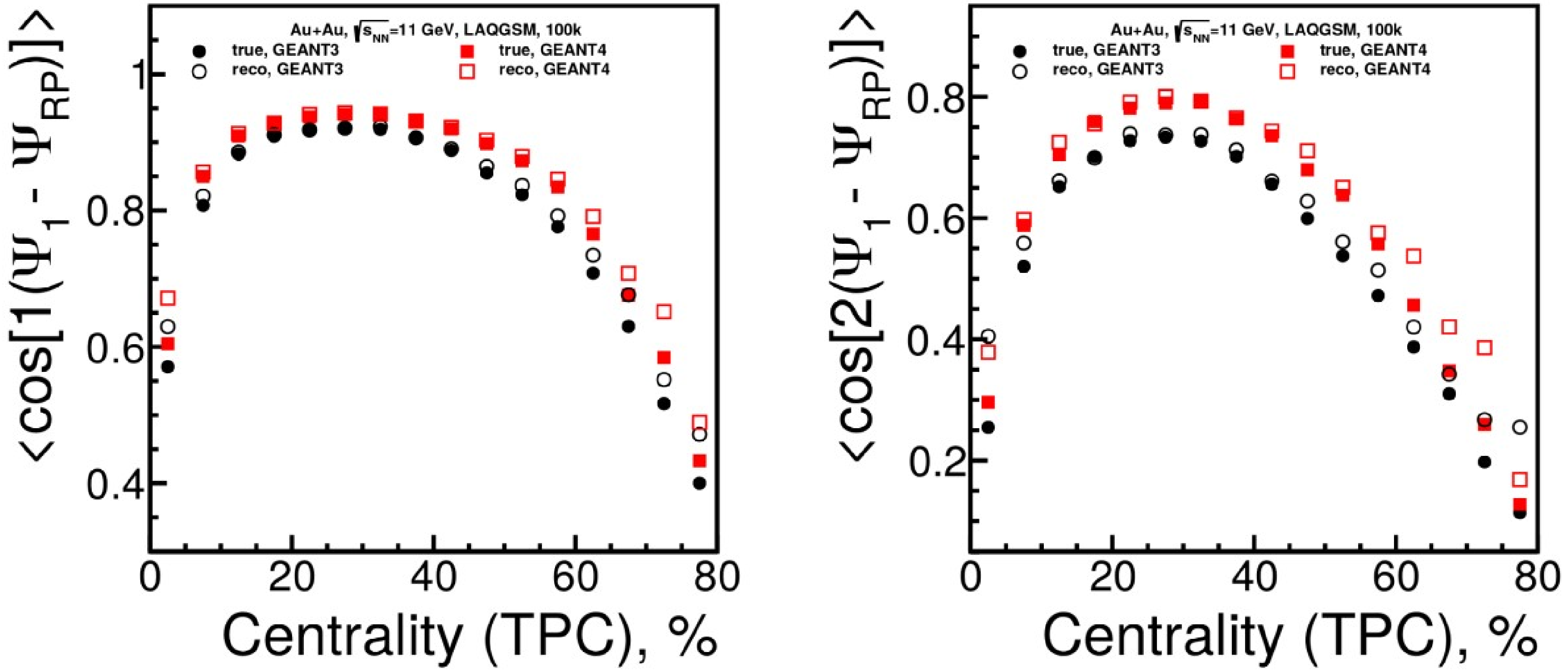




See talk by A. Taranenko

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

Resolution correction factor: GEANT3 vs GEANT4 comparison



GEANT4 has more realistic hadronic shower simulation
In the future: use models with fragments in the spectator area

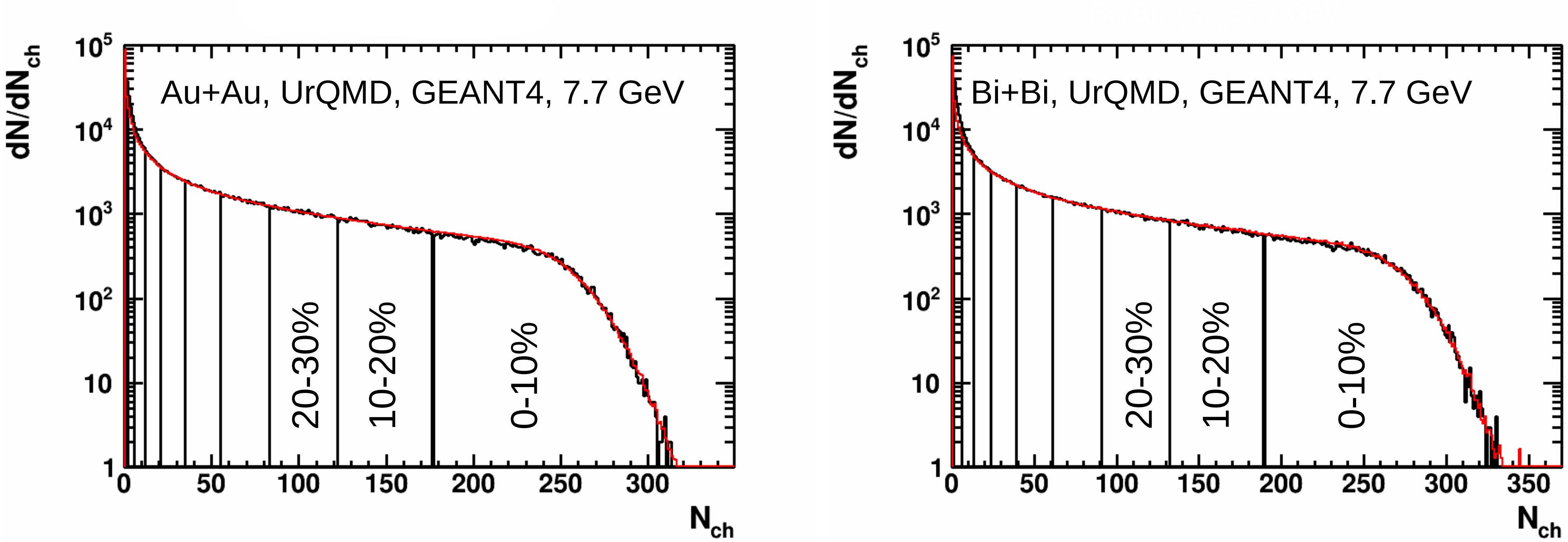
Summary

- Full reconstruction chain was implemented:
  - Combined particle identification based on TPC and TOF
  - Realistic hadronic simulation (GEANT4)
  - Corrections allow us to perform flow measurements even with non-uniform acceptance
- Event plane from FHCal and TPC, scalar product from TPC
- Reconstructed v_1,v_2 are in agreement with MC generated data for Au+Au and Bi+Bi

Thank you for your attention!

Backup slides

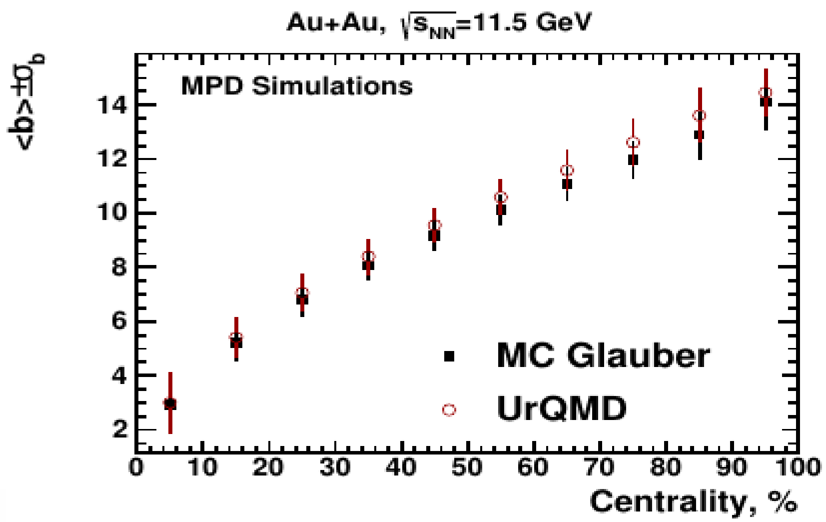
MC Glauber Centrality Framework for MPD

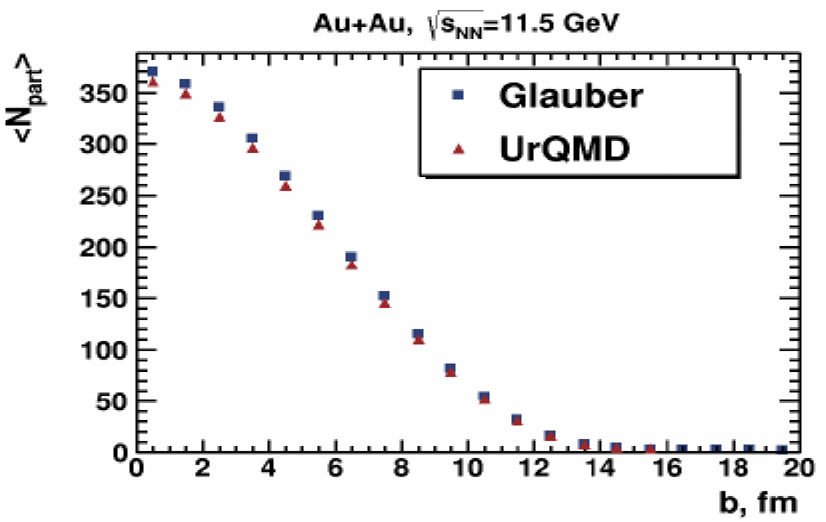


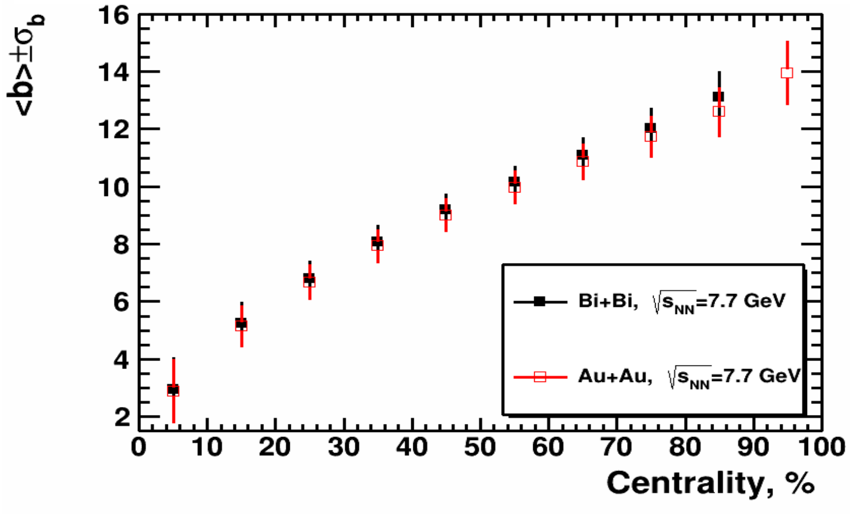
This centrality procedure was used in CBM, NA49, and NA61/SHINE: Acta Phys.Polon.Supp. 10 (2017) 919
Implemantation in MPD: https://github.com/IlyaSegal/NICA

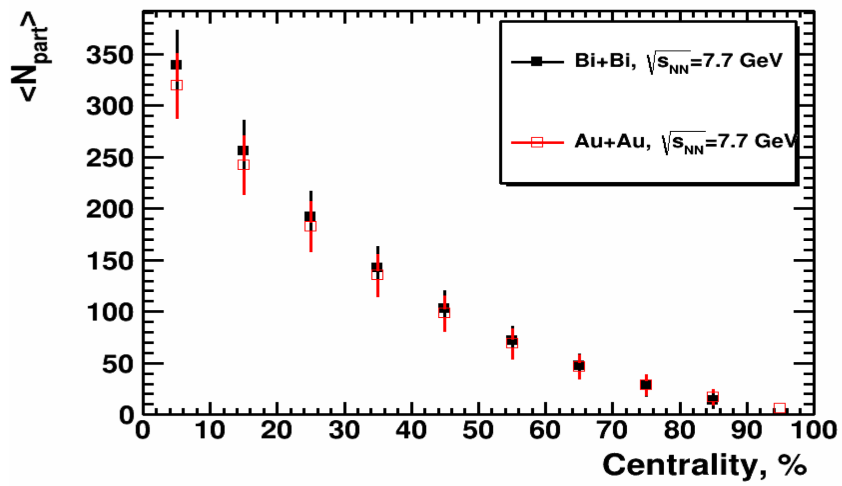
Parfenov. P , Selyuzhenkov I., Segal. I

MC Glauber Centrality Framework

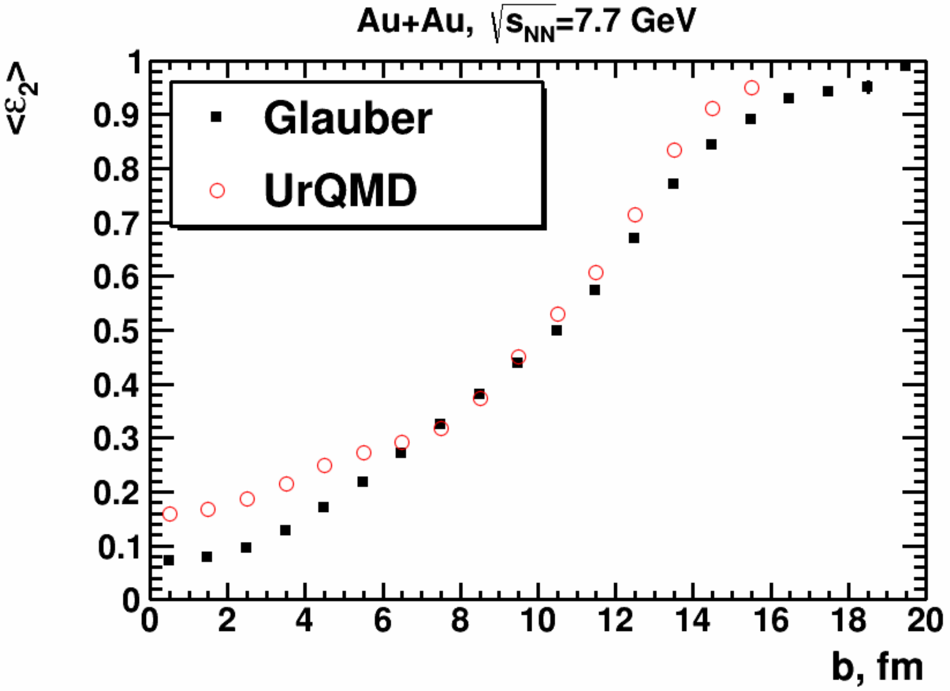


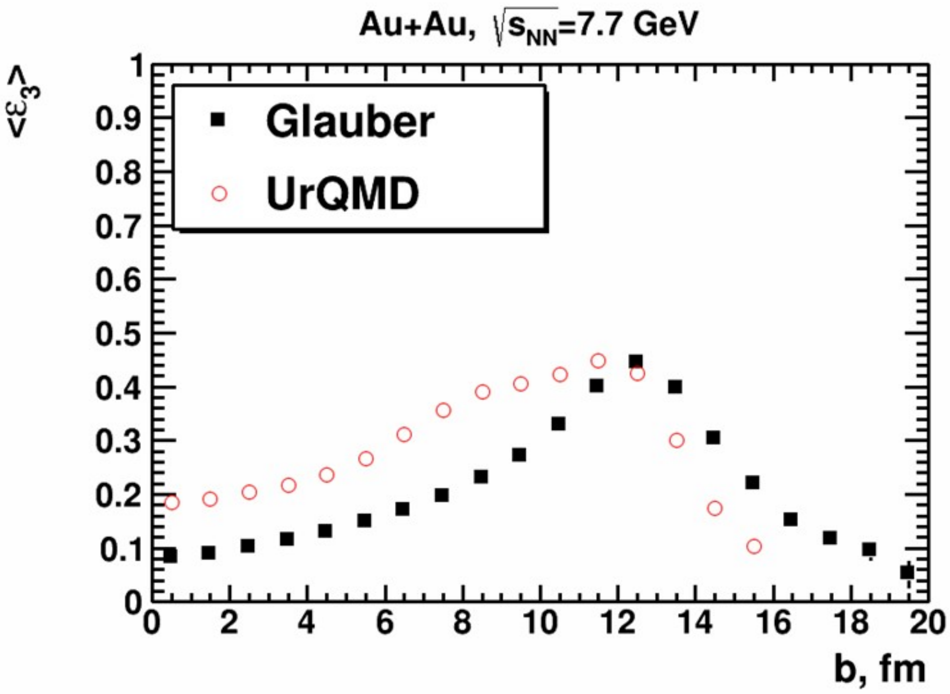






Eccentricity: Comparison w/ UrQMD

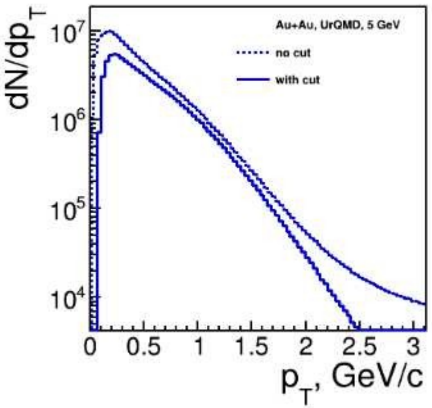


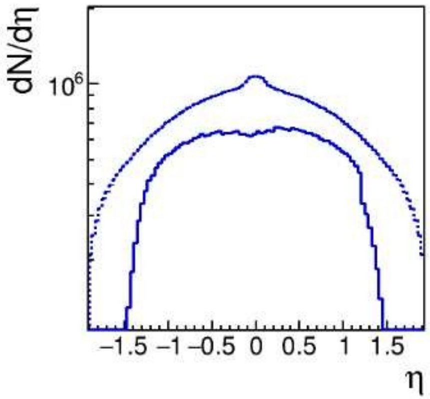


Notable difference between MC Glauber and UrQMD eccentricities

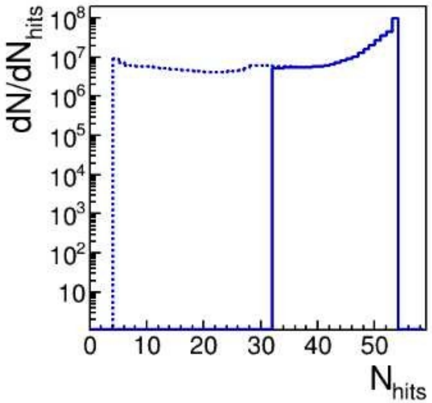
Common data format for all models : UrQMD, SMASH, PHSD, JAM, AMPT

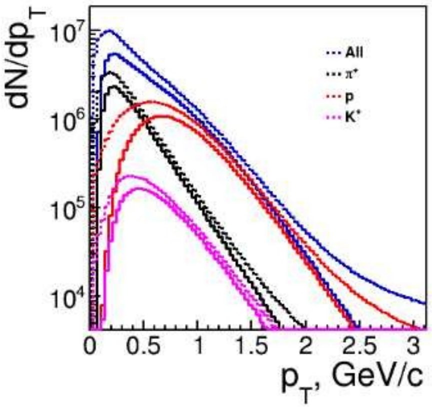
Track selection

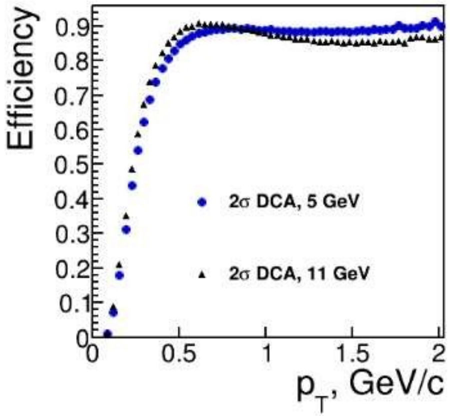




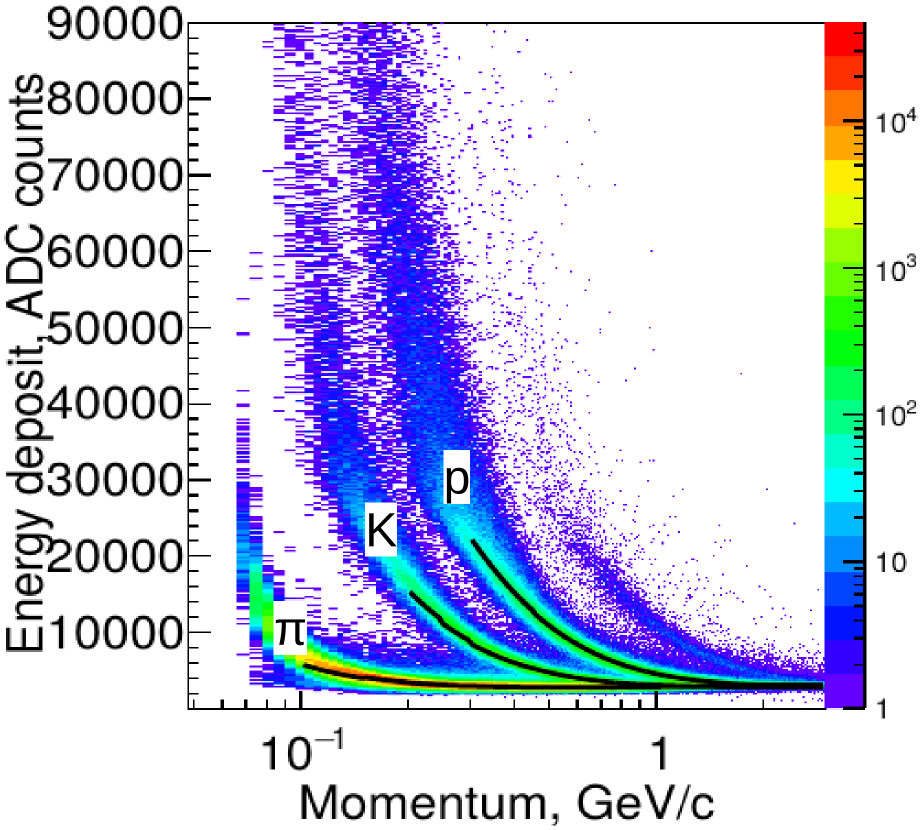
- $N_{TPC\ hits}$ >32
- $|p_T|$<3
- $|\eta|$<1.5
- PID based on TPC+TOF (MpdPid)

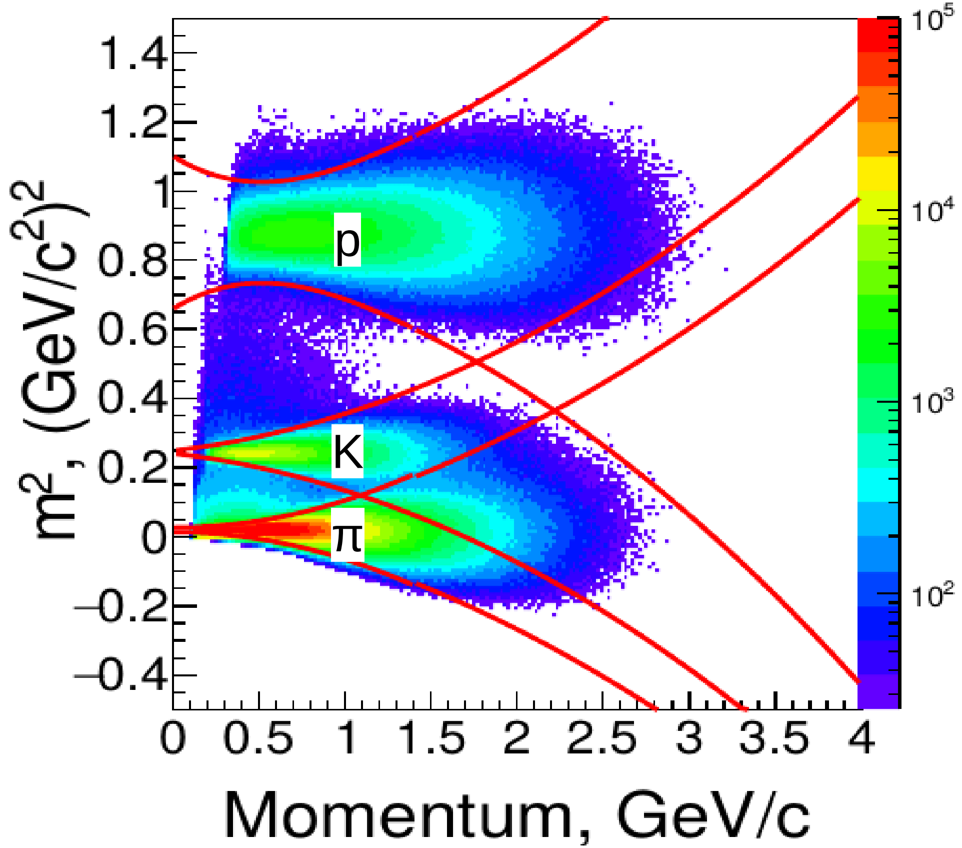






Particle identification based on TPC + TOF

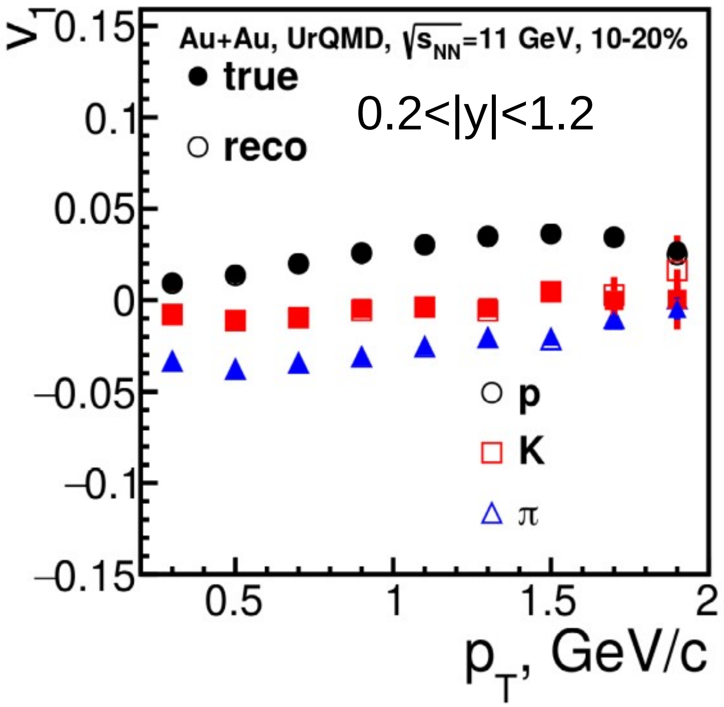


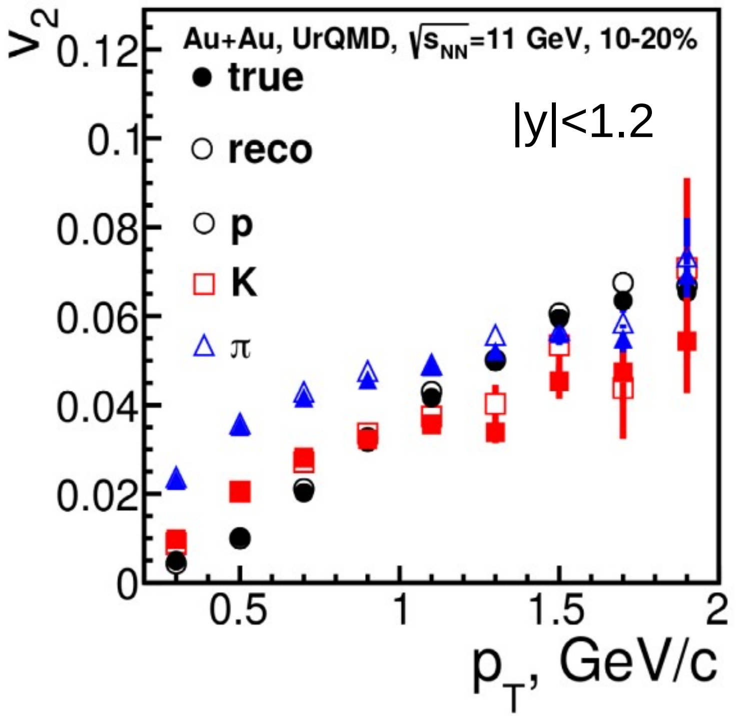


Low momentum:
dE/dx from TPC

High momentum:
m^2 estimated from TOF signal

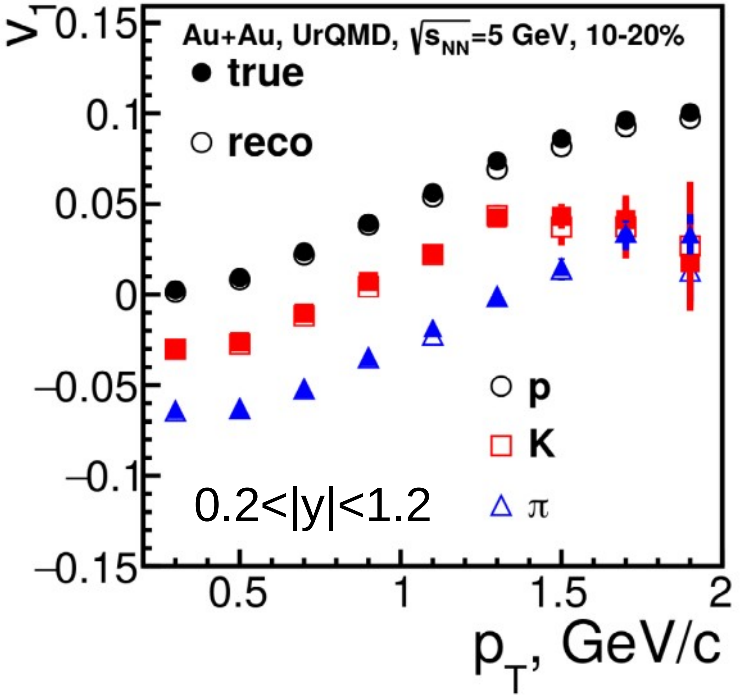
$v_{1,2}\,(p_T)$, Au+Au, $\sqrt{s_{NN}} = 11$ GeV

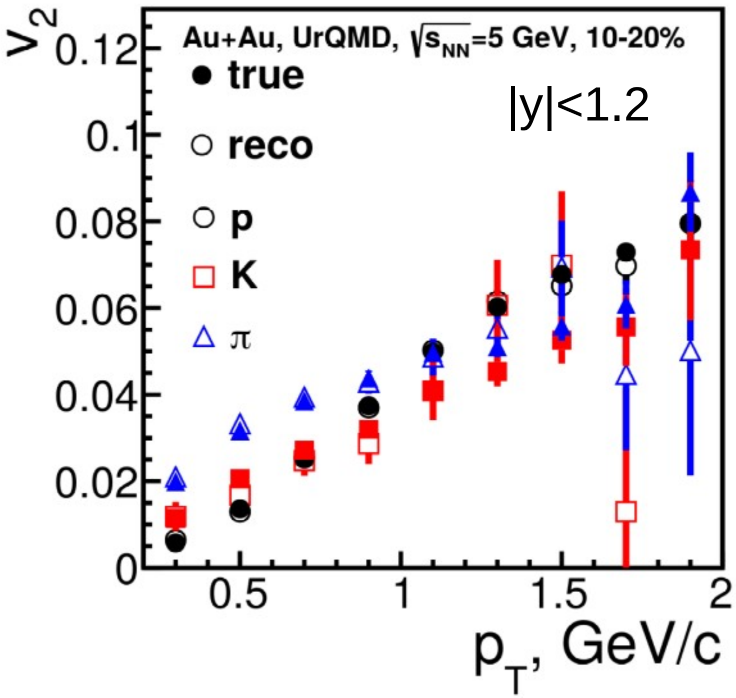




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

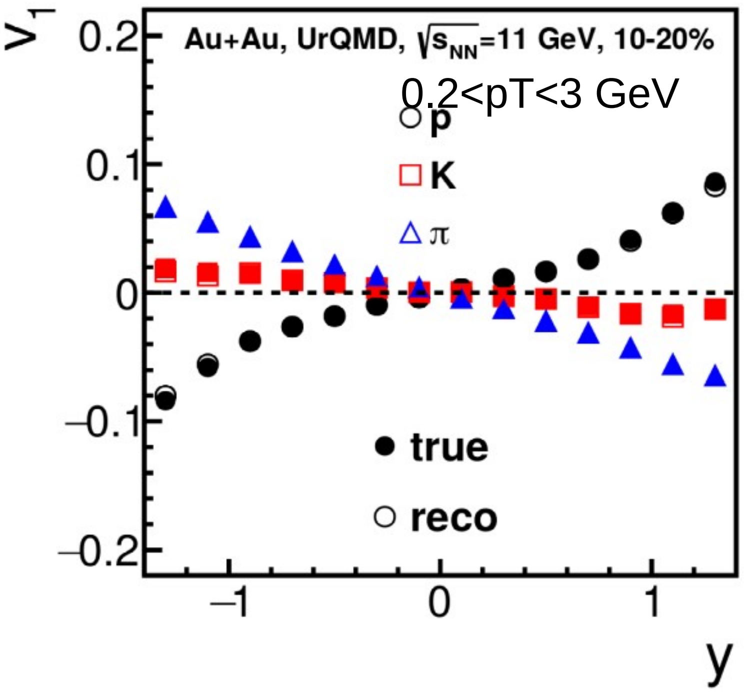
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV

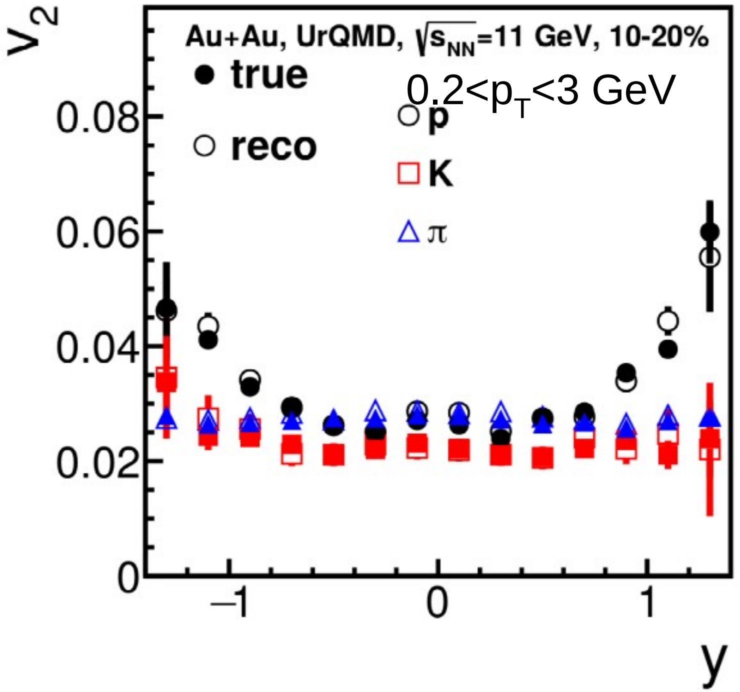




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

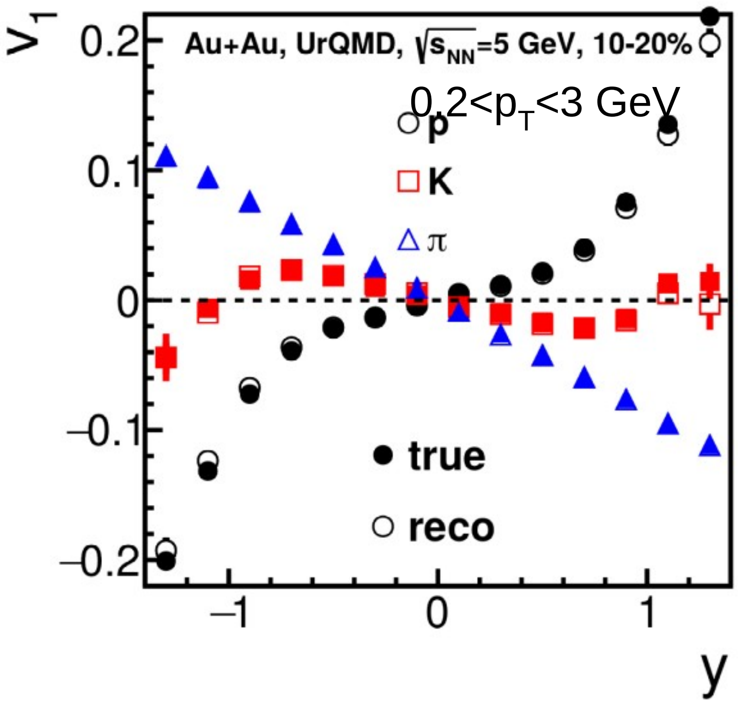
$v_{1,2}$ (y), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

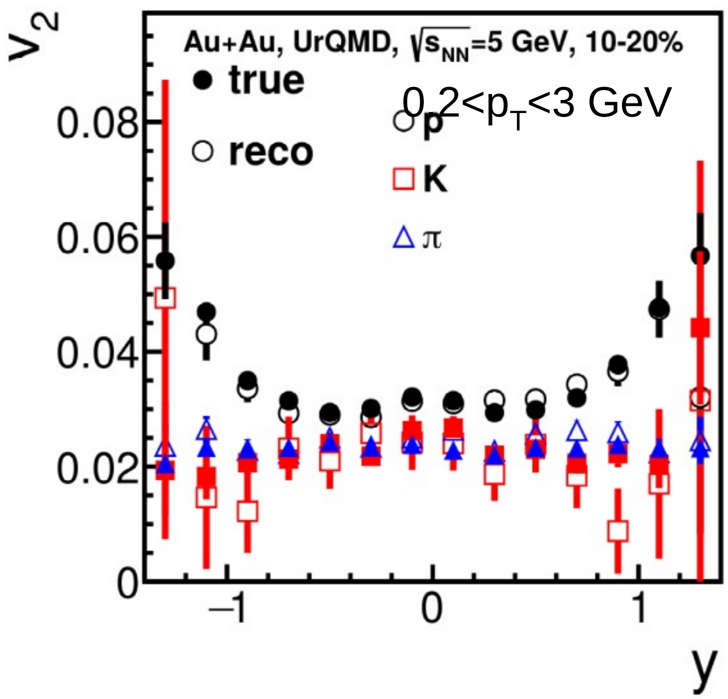




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

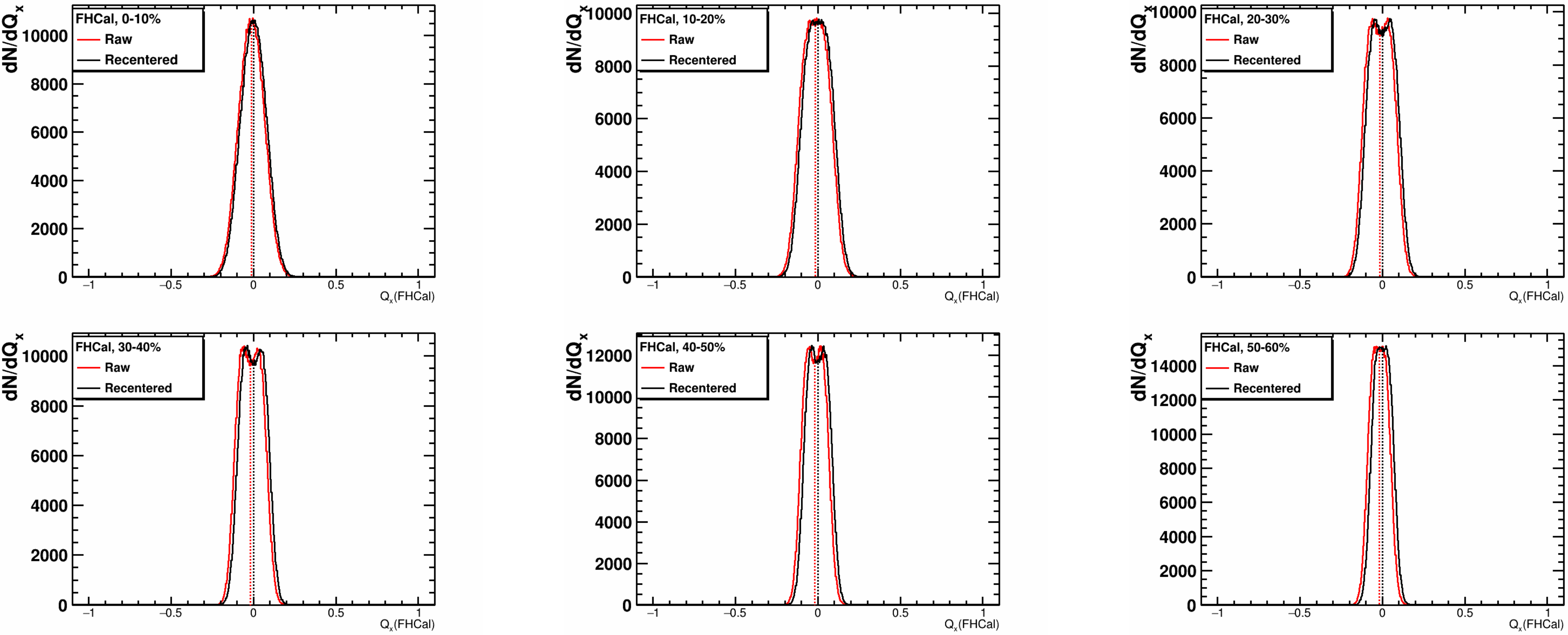
$v_{1,2}$ (y), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV



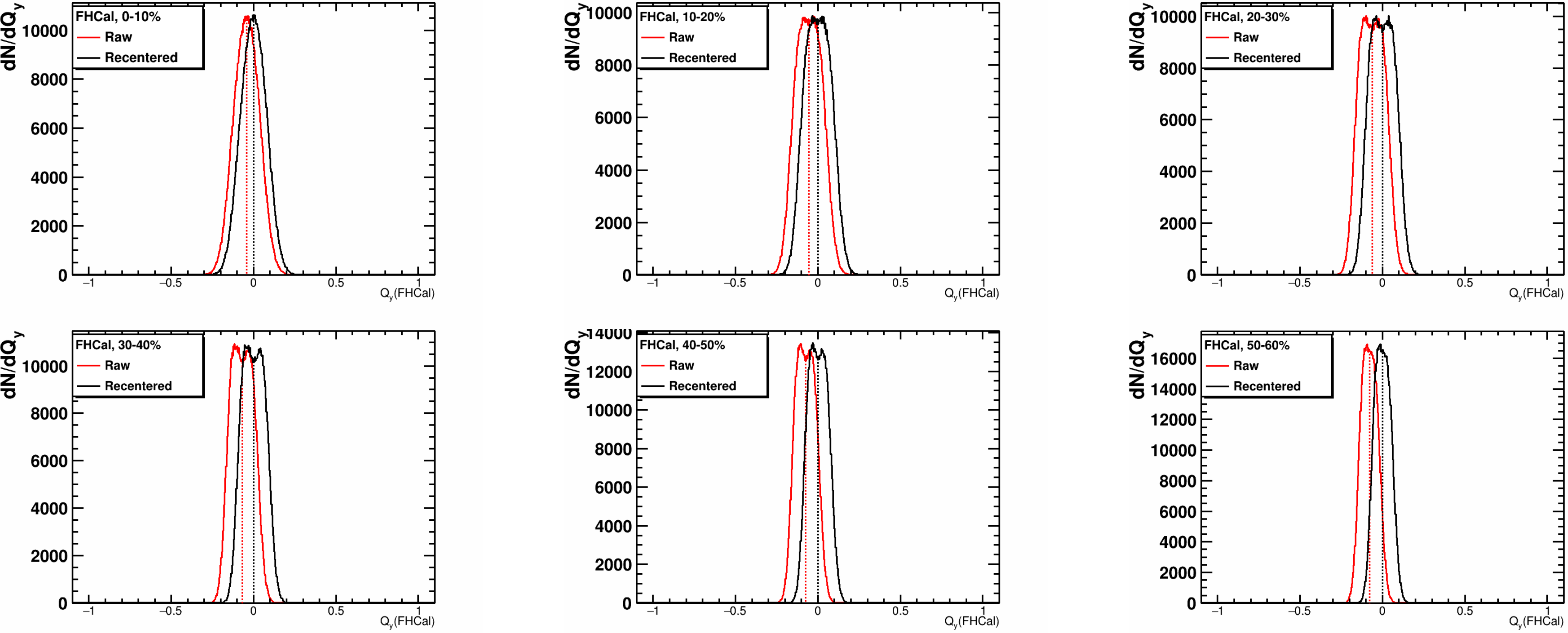


Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

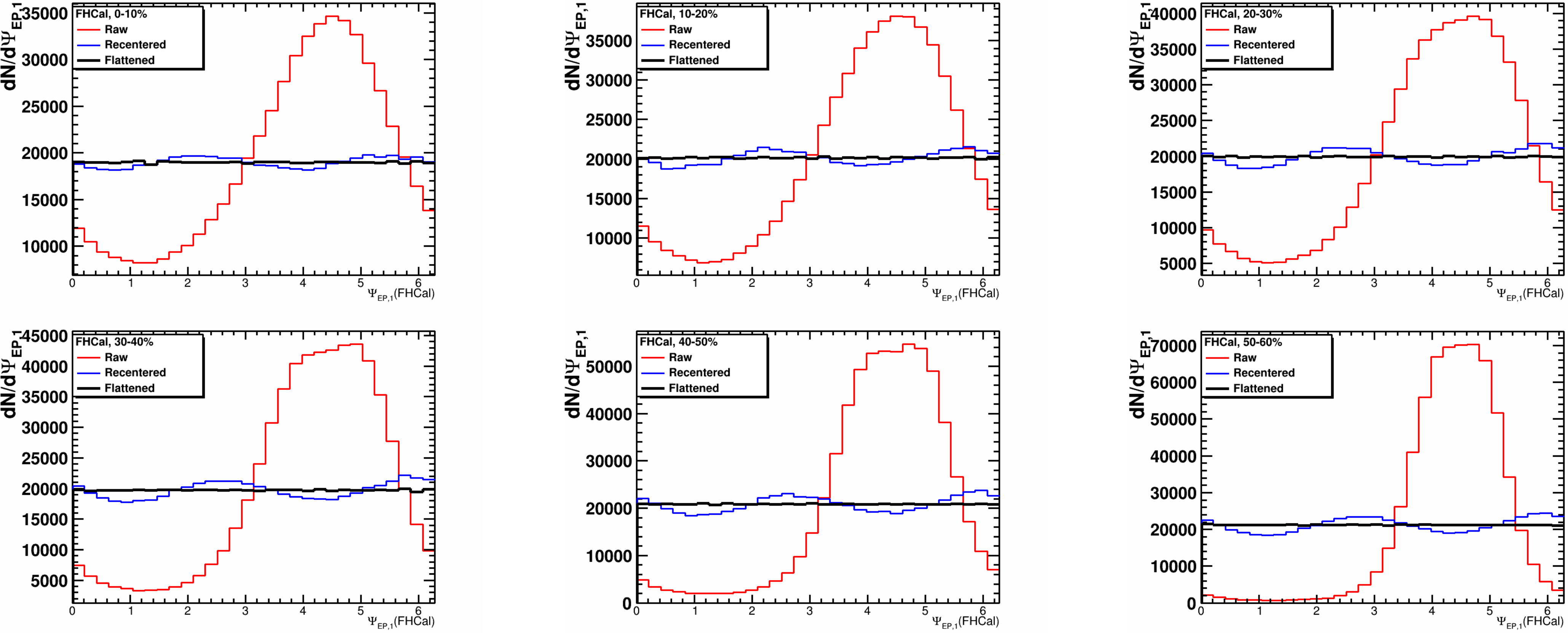
FHCal EP: Q_x


FHCal, 0-10%
FHCal, 10-20%
FHCal, 20-30%
FHCal, 30-40%
FHCal, 40-50%
FHCal, 50-60%
Raw
Recentered
dN/dQx
Qx(FHCal)

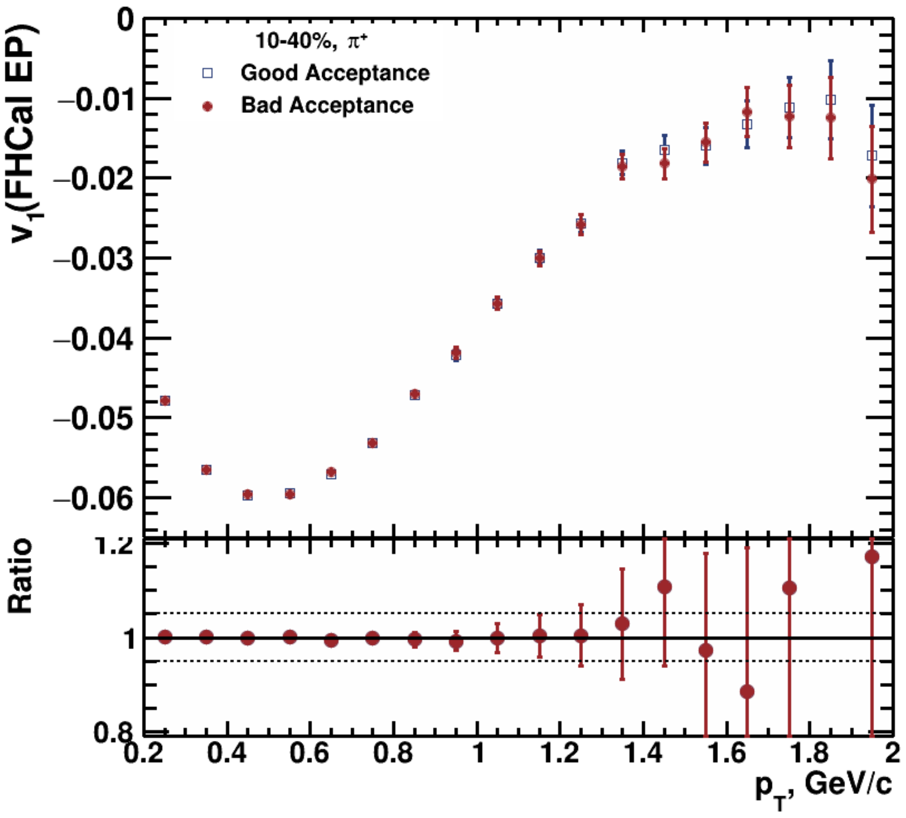
Tpc EP: Q_y

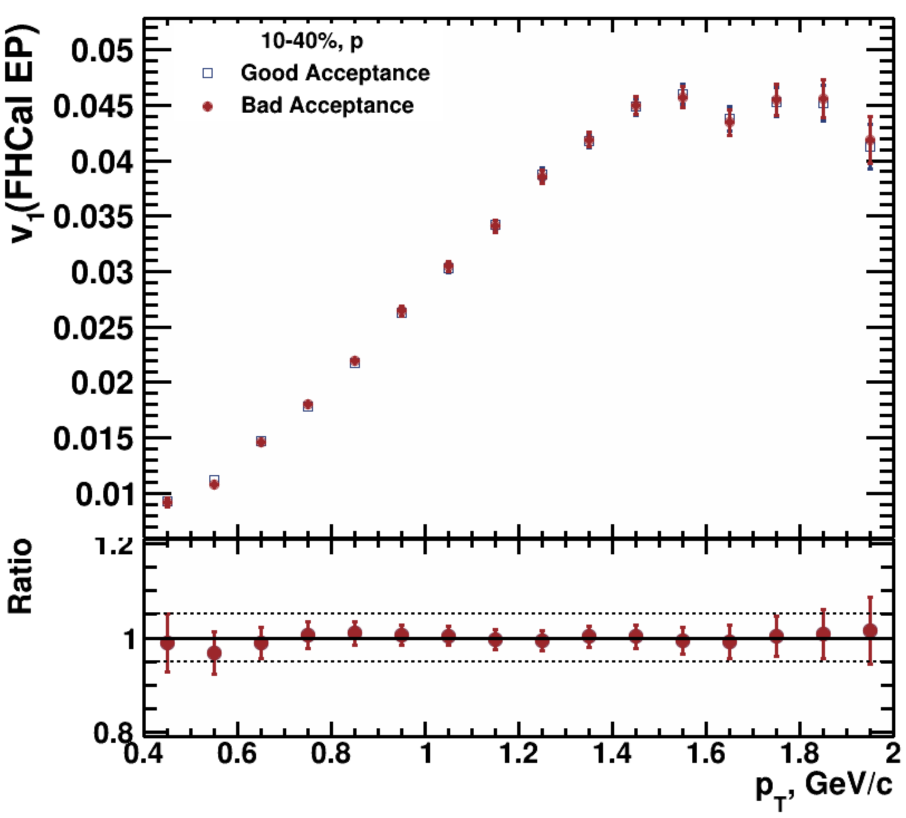

FHCal, 0-10%
FHCal, 10-20%
FHCal, 20-30%
FHCal, 30-40%
FHCal, 40-50%
FHCal, 50-60%
Raw
Recentered
dN/dQy
Qy(FHCal)

FHCal EP: Ψ_{EP}

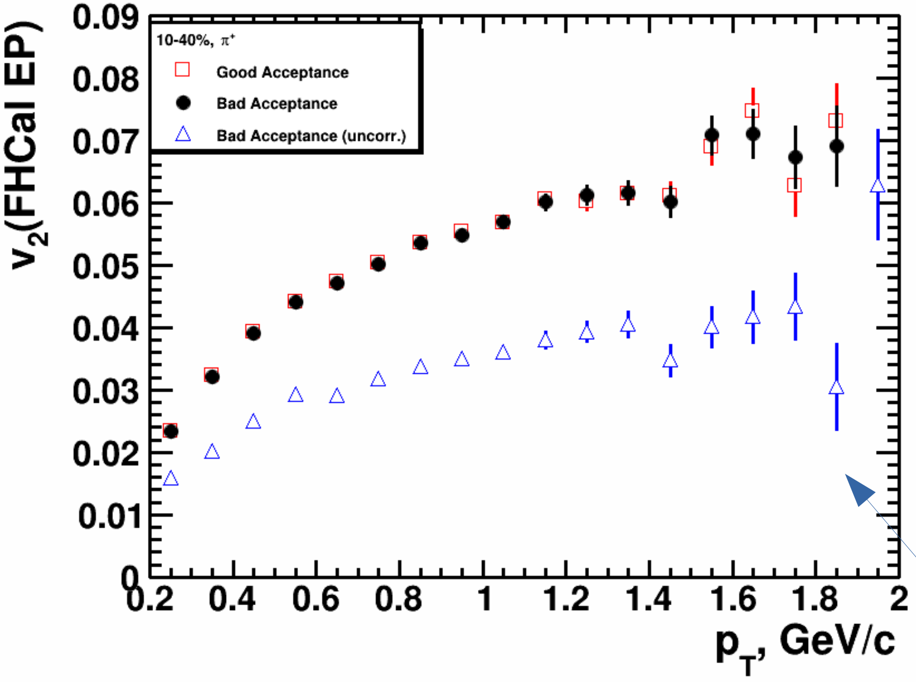


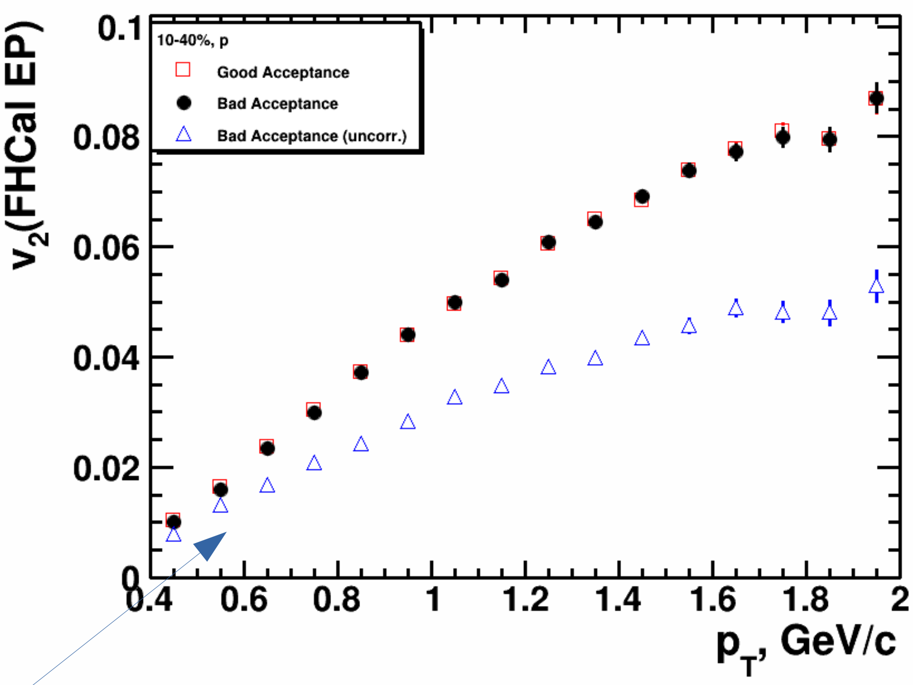
FHCal EP: $v_1(p_T)$





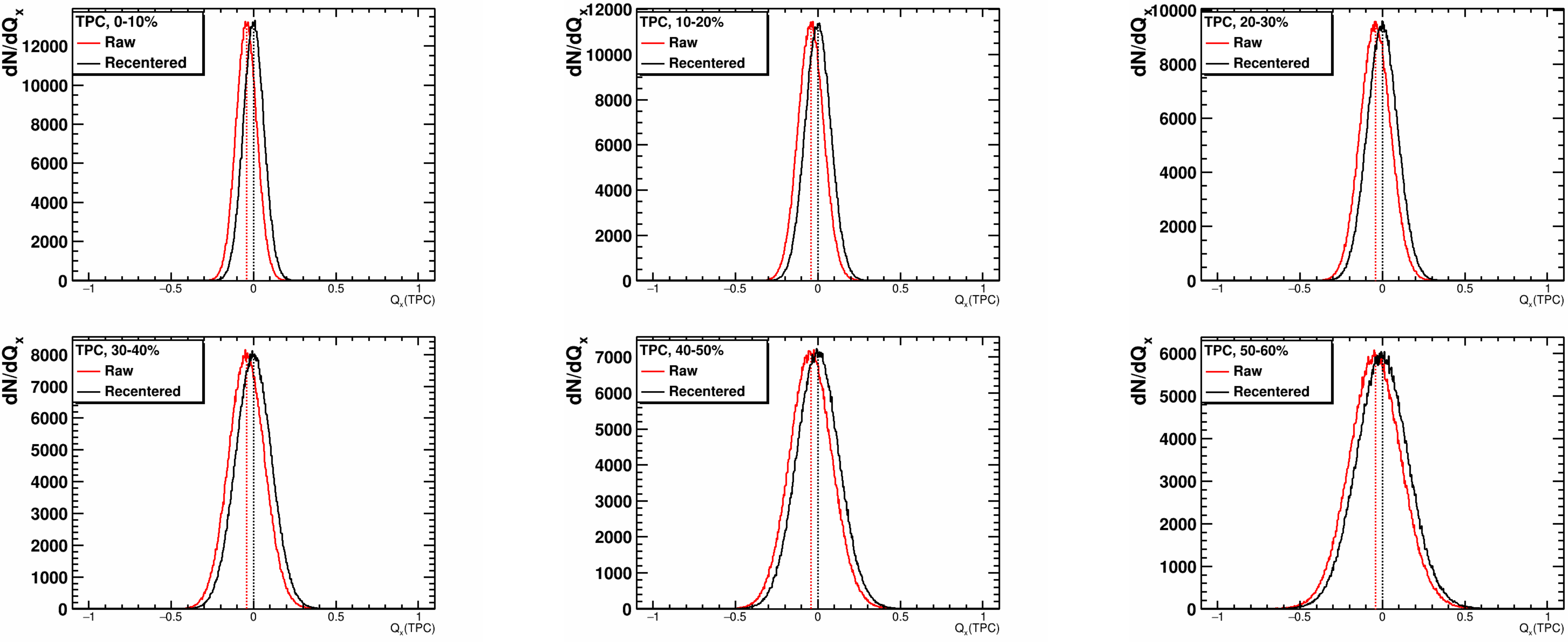
FHCal EP: $v_2(p_T)$ (with uncorr.)





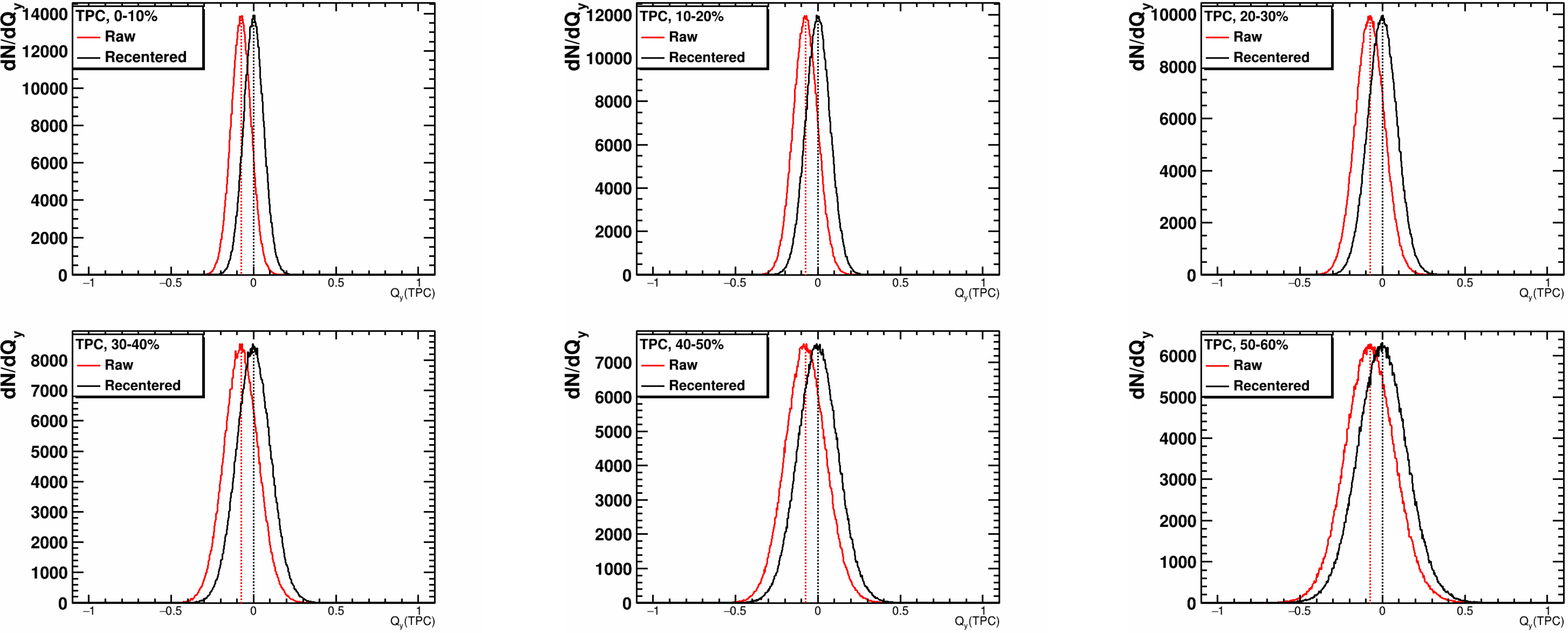
If no corrections were applied
(recentering, flattening)

Tpc EP: Q_x



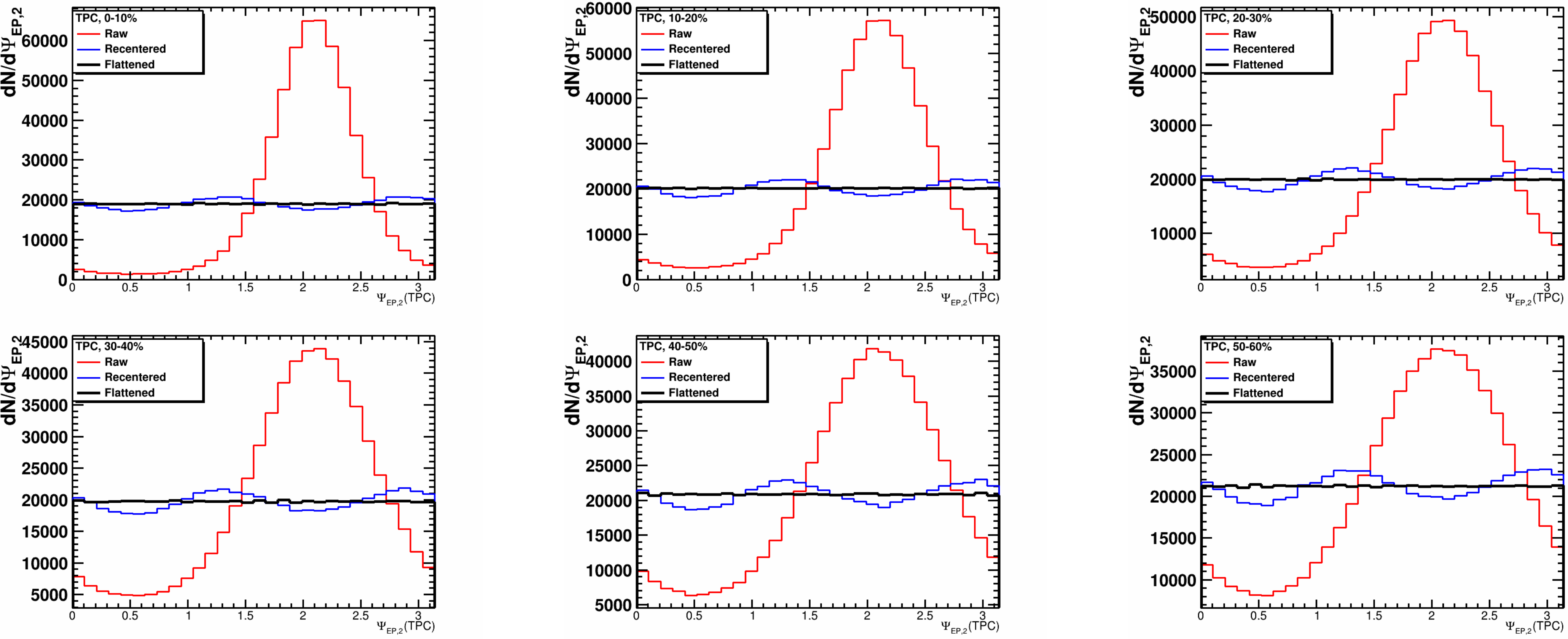
TPC, 0-10%
TPC, 10-20%
TPC, 20-30%
TPC, 30-40%
TPC, 40-50%
TPC, 50-60%
Raw
Recentered
dN/dQx
Qx(TPC)

Tpc EP: Q_y

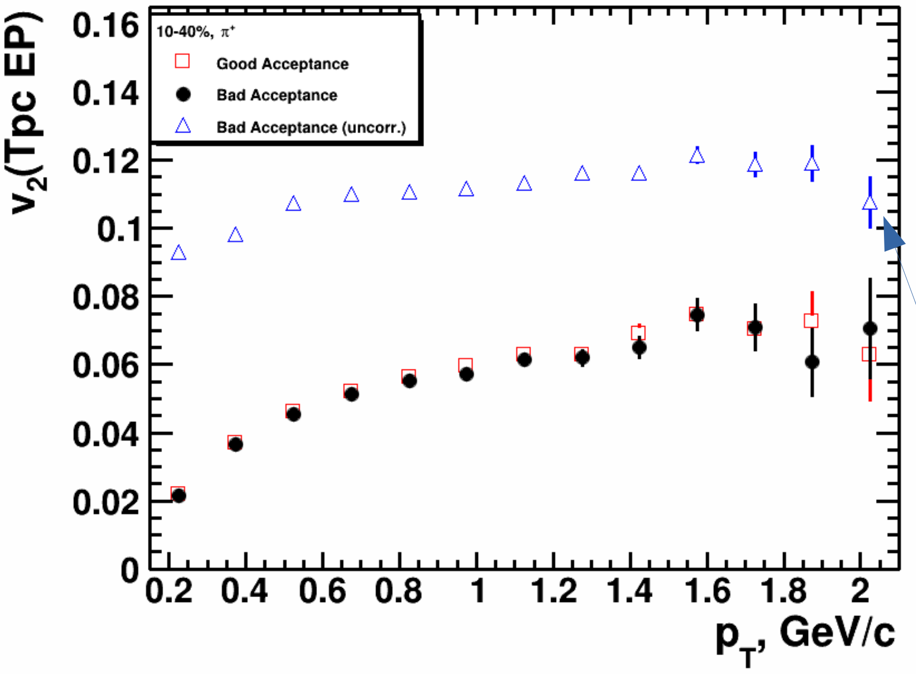


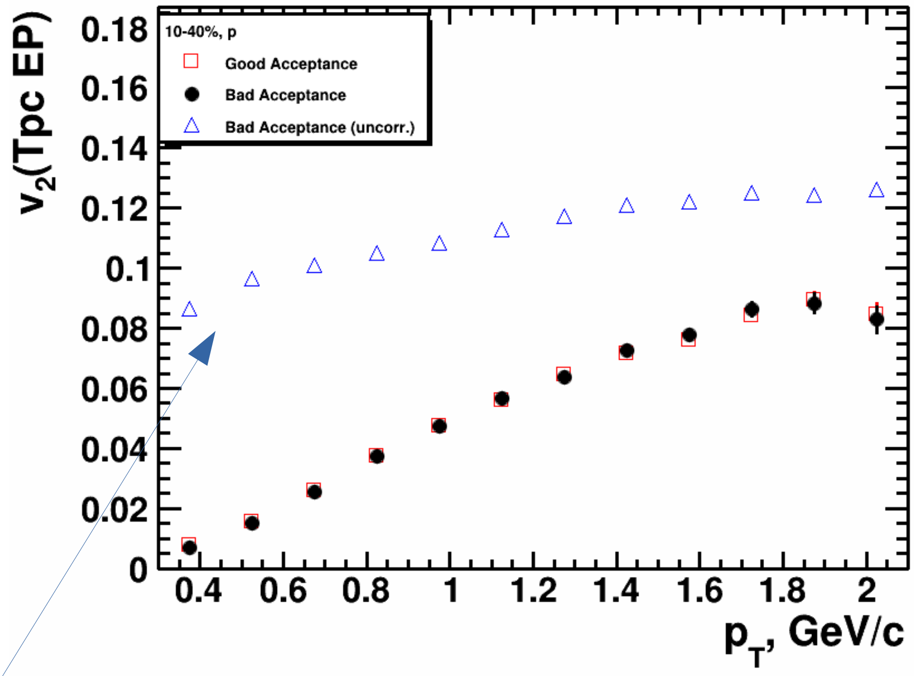
TPC, 0-10%
Raw
Recentered
TPC, 10-20%
Raw
Recentered
TPC, 20-30%
Raw
Recentered
TPC, 30-40%
Raw
Recentered
TPC, 40-50%
Raw
Recentered
TPC, 50-60%
Raw
Recentered
dN/dQy
Qy(TPC)

Tpc EP: Ψ_{EP}


TPC, 0-10%
TPC, 10-20%
TPC, 20-30%
TPC, 30-40%
TPC, 40-50%
TPC, 50-60%
Raw
Recentered
Flattened
$dN/d\Psi_{EP,2}$
$\Psi_{EP,2}$(TPC)

Tpc EP: $v_2(p_T)$ (with uncorr.)





If no corrections were applied
(recentering, flattening)

v_2 EP vs. SP methods