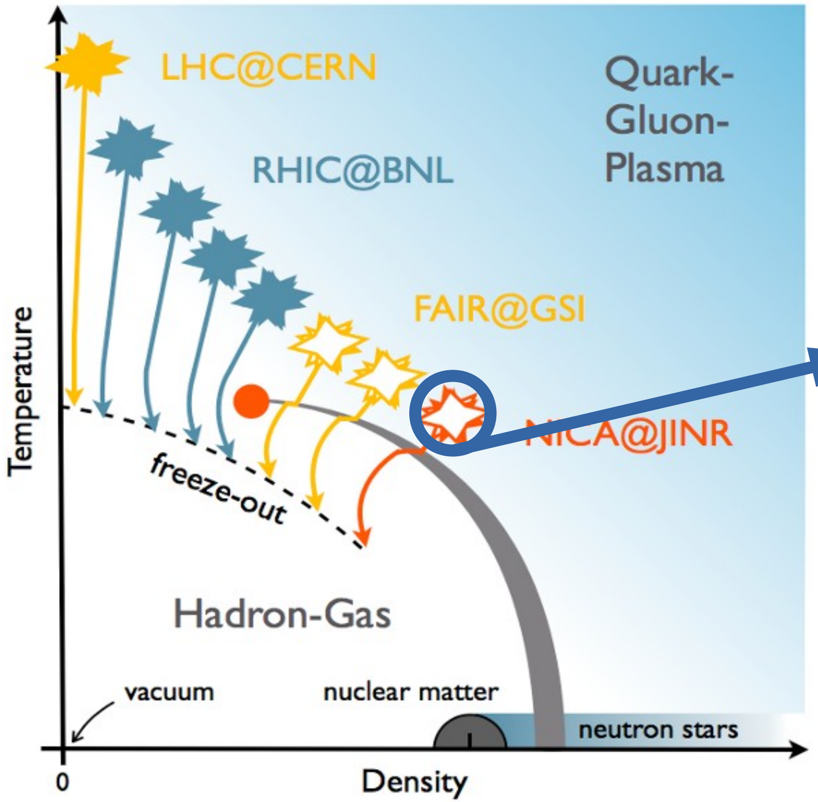
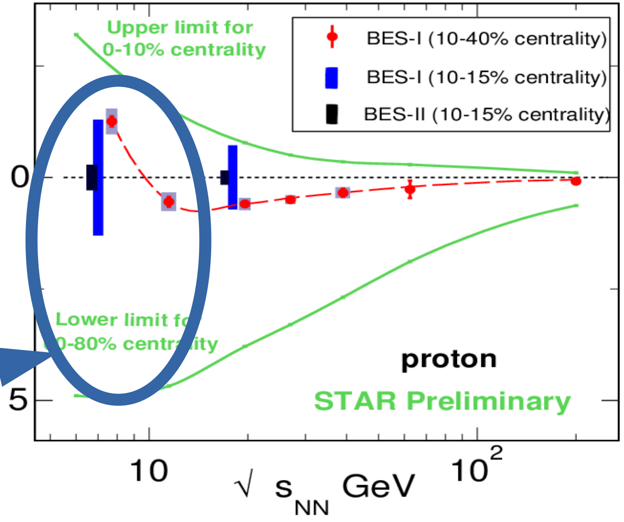
Performance of anisotropic flow studies at MPD (NICA)

Peter Parfenov (MEPhI, INR RAS)
Ilya Selyuzhenkov (GSI, MEPhI)
Arkadiy Taranenko (MEPhI)

AYSS-2019
JINR, Dubna, Russia
15.04.2019

Directed flow at NICA energies

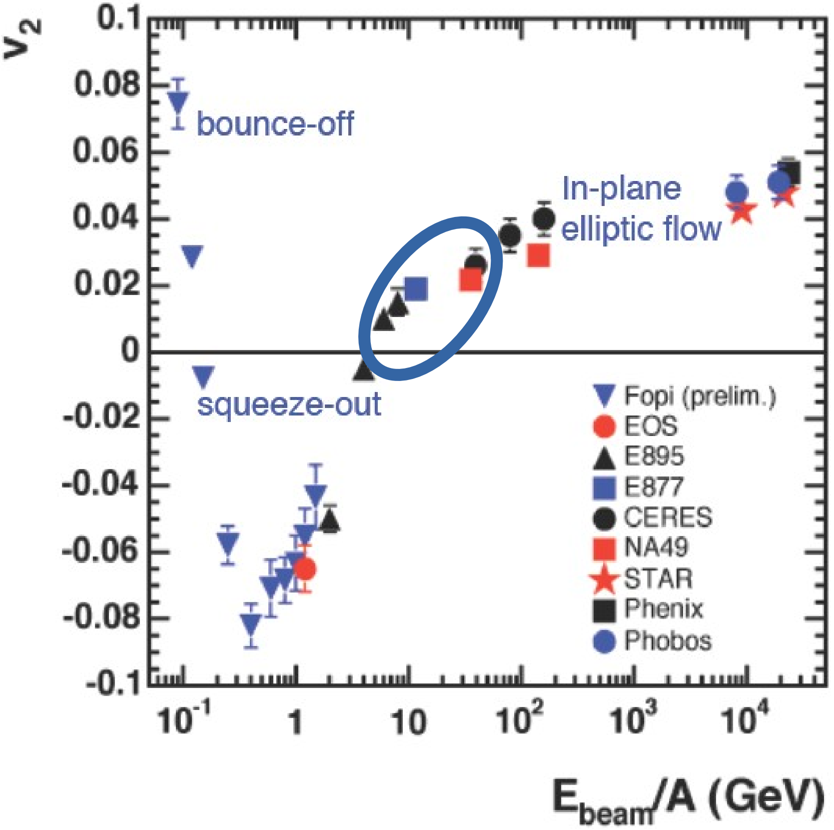


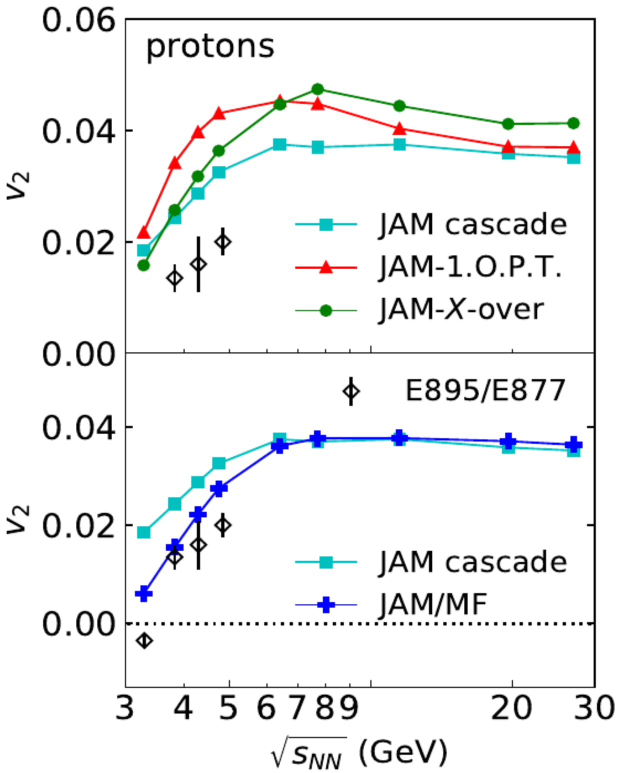


Strong centrality dependence of directed flow of protons is expected at NICA energy range based on STAR preliminary data

Non-monotonic dv_1/dy behavior can signal the phase transition

Elliptic flow at NICA energies



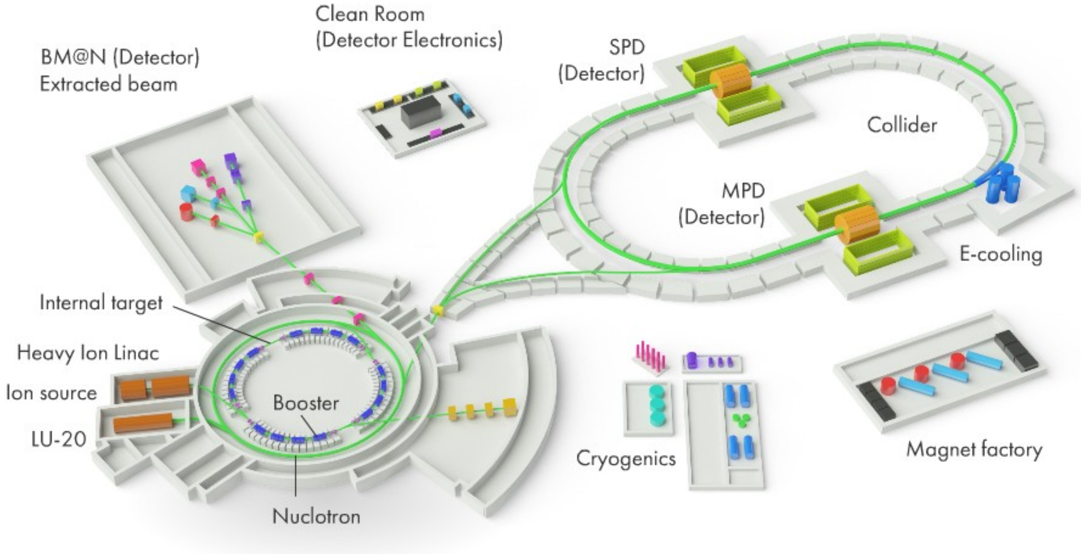


Nara, Yasushi et al. Eur.Phys.J. A54 (2018)

At Nuclotron-NICA energy range elliptic flow as a function of energy changes sign

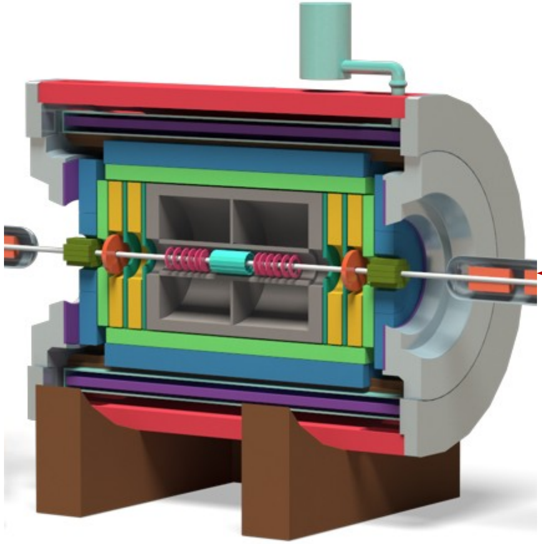
Both directed and elliptic flow can signal a first order phase transition

MPD experiment at NICA

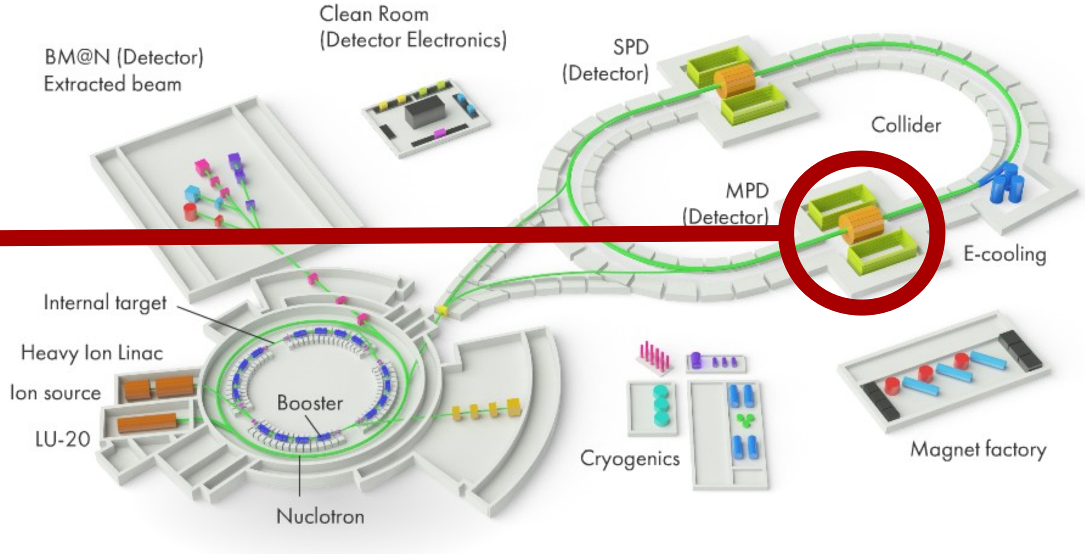


NICA complex

MPD experiment at NICA

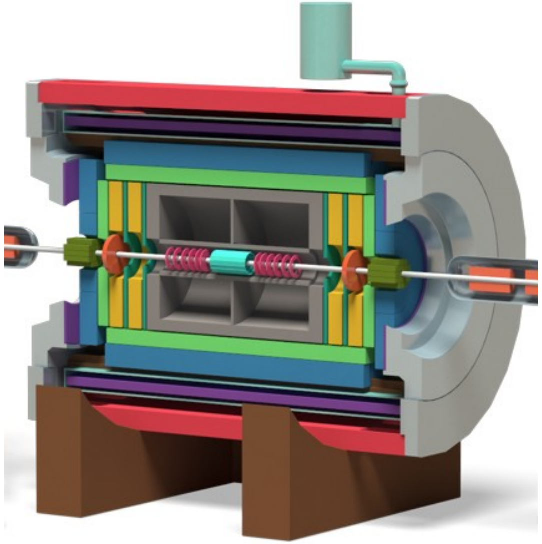


Multi Purpose Detector (MPD)



NICA complex

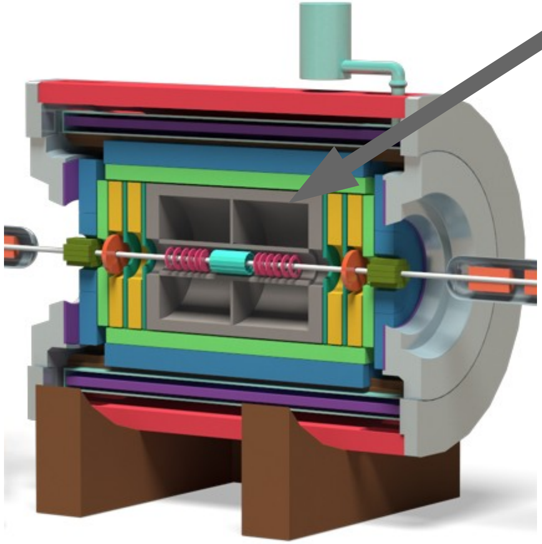
MPD experiment at NICA

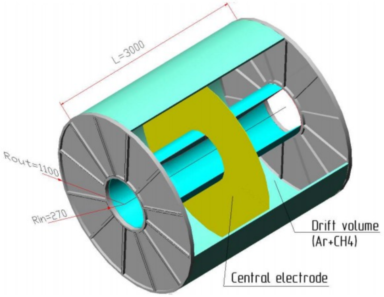


Multi Purpose Detector (MPD)

MPD experiment at NICA

Time projection chamber (TPC)





Multi Purpose Detector (MPD)

- **TPC** (l = 340 cm, r_{in} = 54 cm):
  Charged particles at midrapidity

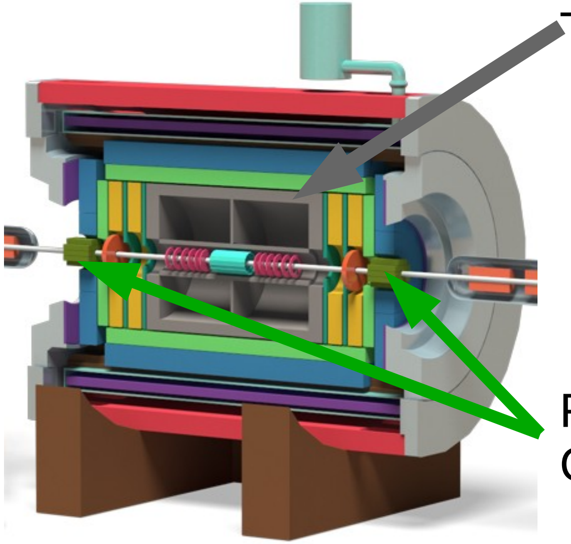
$-1.2<\eta<1.2$

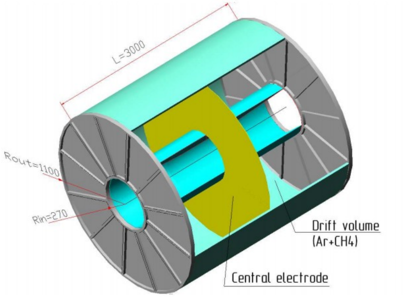
TPC

$0.2<p_T<3$

MPD experiment at NICA

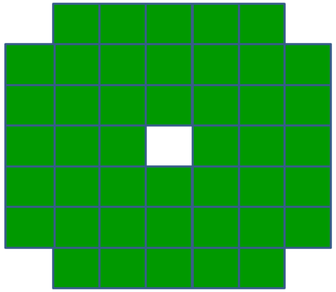
Time projection chamber (TPC)



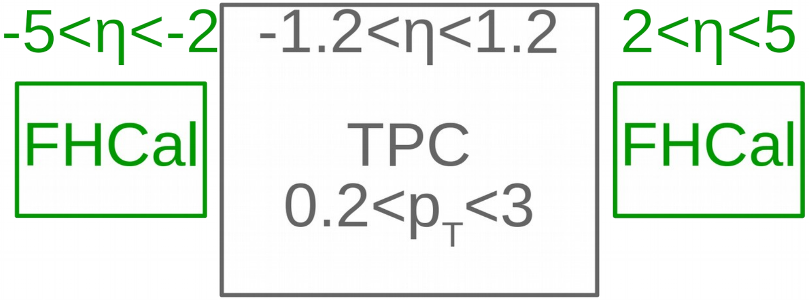


Forward Hadron Calorimeter (FHCal)

Multi Purpose Detector (MPD)



- **TPC** (l = 340 cm, r_{in} = 54 cm): Charged particles at midrapidity
- **FHCal** (44 15×15 cm modules): Hadrons at forward rapidity



Setup, event and track selection

UrQMD
LAQGSM

→ GEANT3
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
- ...

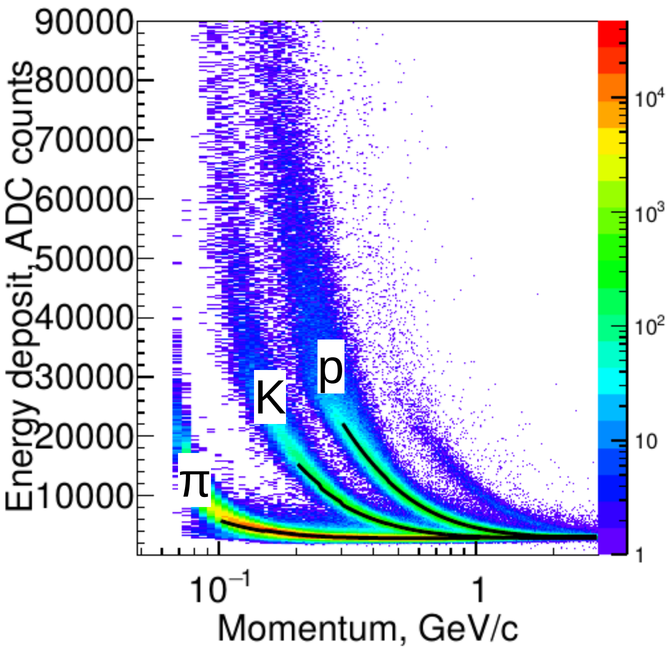
Event classification:
- Track multiplicity
- FHCal energy

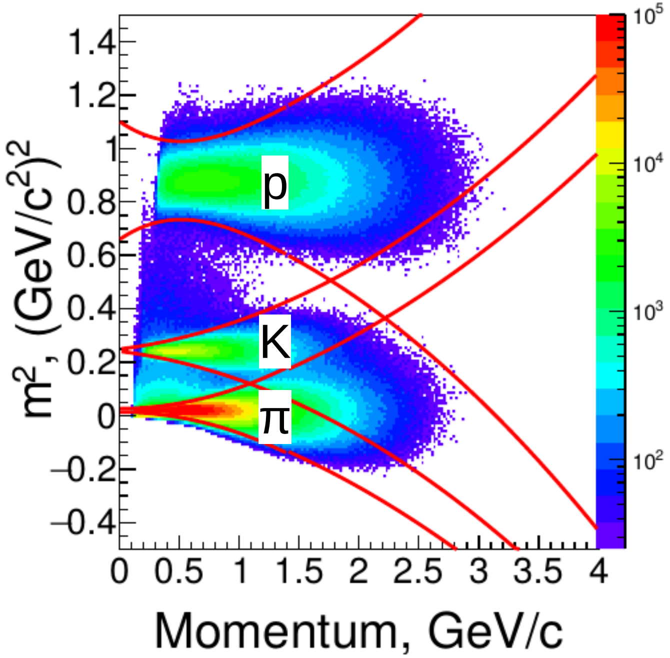
Track selection:
- Primary tracks (2σ DCA cut)
- $N_{TPC\ hits} > 32$
- $0.2 < p_T < 2$ GeV/c
- $|\eta| < 1.5$
- PID based on TPC+TOF (MpdPid)

MPDRoot, May 2018

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

Combined particle identification based on TPC + TOF



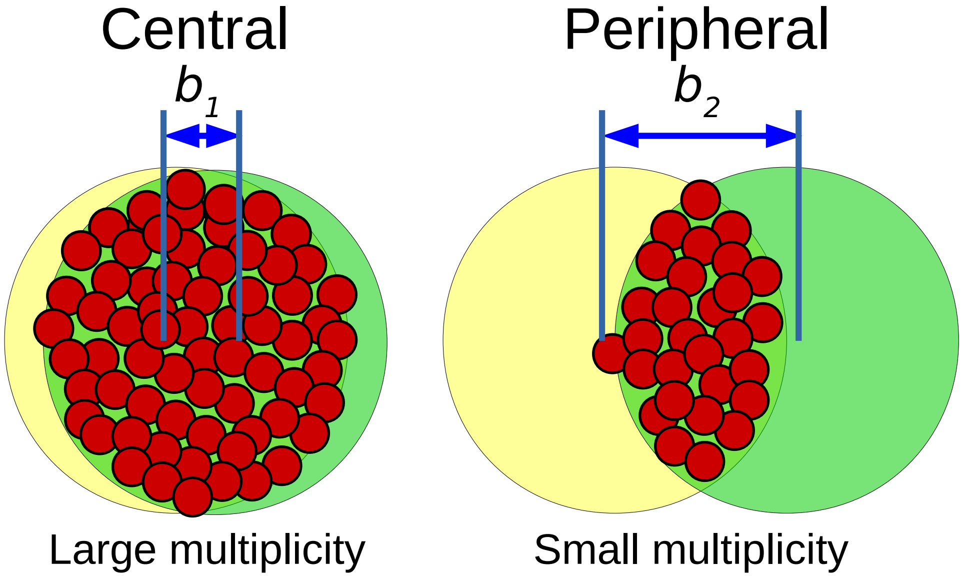


Low momentum:
dE/dx from TPC

High momentum:
m^2 estimated from TOF signal

Centrality determination

Centrality determination



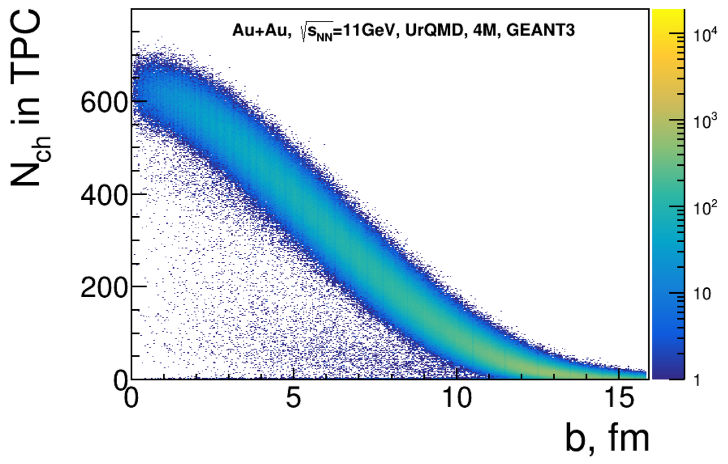
Impact parameter is not known

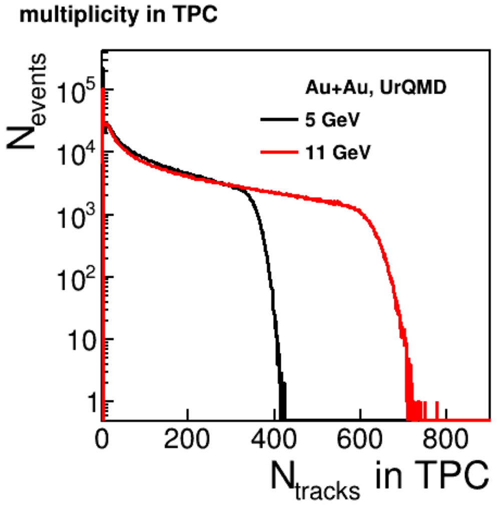
Experimentally:

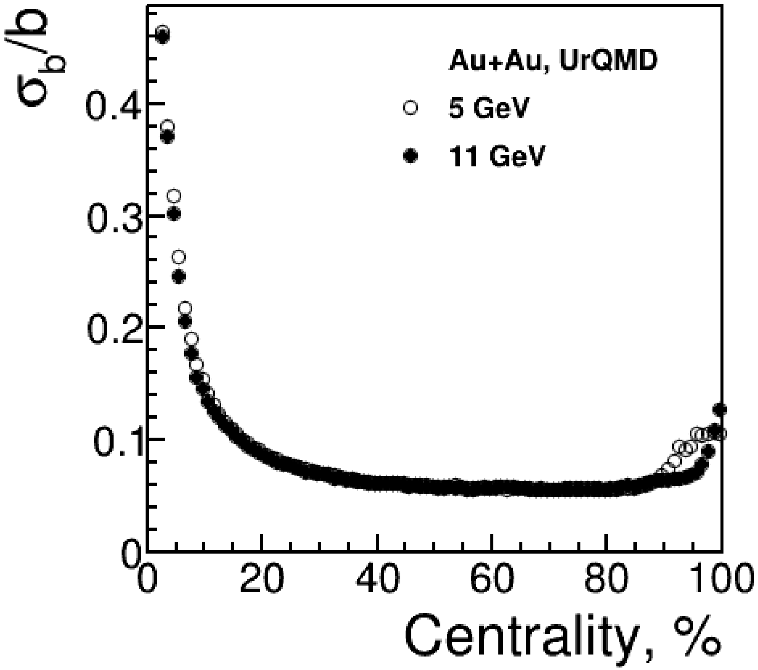
Centrality classes determined based on a fraction of a total number of nucleus-nucleus inelastic collisions

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

Centrality estimation using multiplicity distribution in TPC







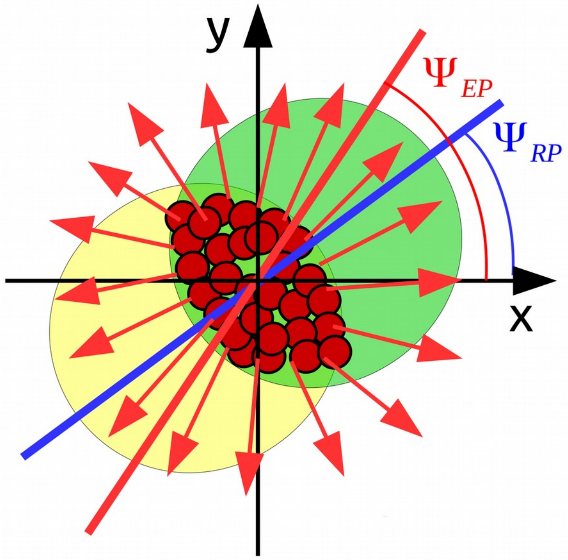
- Good correlation between *b* and TPC Multiplicity
- Events were grouped in centrality classes based on multiplicity distribution

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

Anisotropic flow performance

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:



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

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

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

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

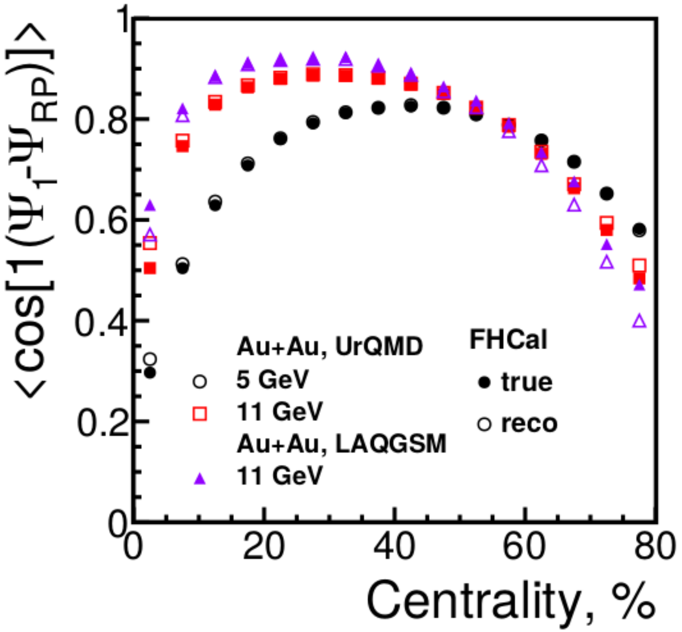
$$\Psi_n^{EP}=\frac{1}{n}\tan^{-1}\left(\frac{Q_{n,Y}}{Q_{n,X}}\right)$$

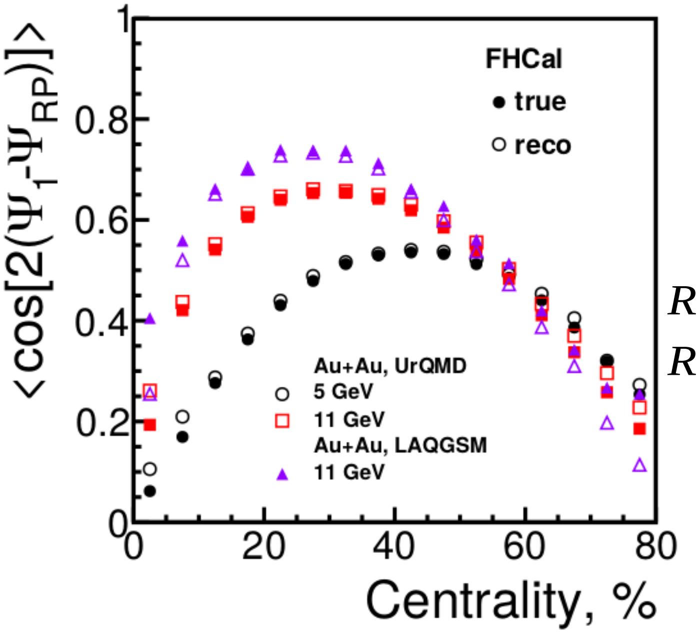
$$v_n=\frac{\langle\cos(n(\varphi-\Psi_{n,EP}))\rangle}{R_{n,EP}}$$

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

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

Resolution correction factor





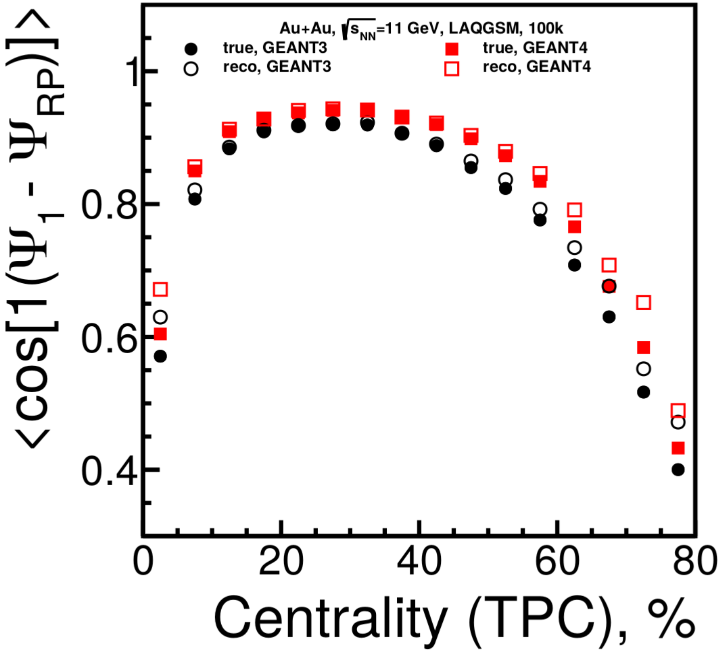
$$v_n = \frac{\langle \cos(n(\varphi - \Psi_{n,EP})) \rangle}{R_{n,EP}}$$

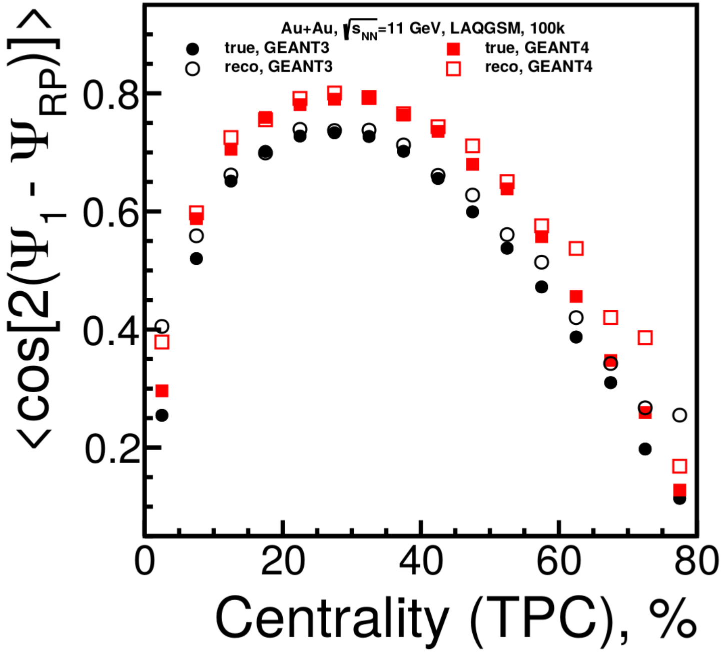
$$R_{n,EP} = \langle \cos(n(\Psi_{n,EP} - \Psi_{RP})) \rangle$$

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

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

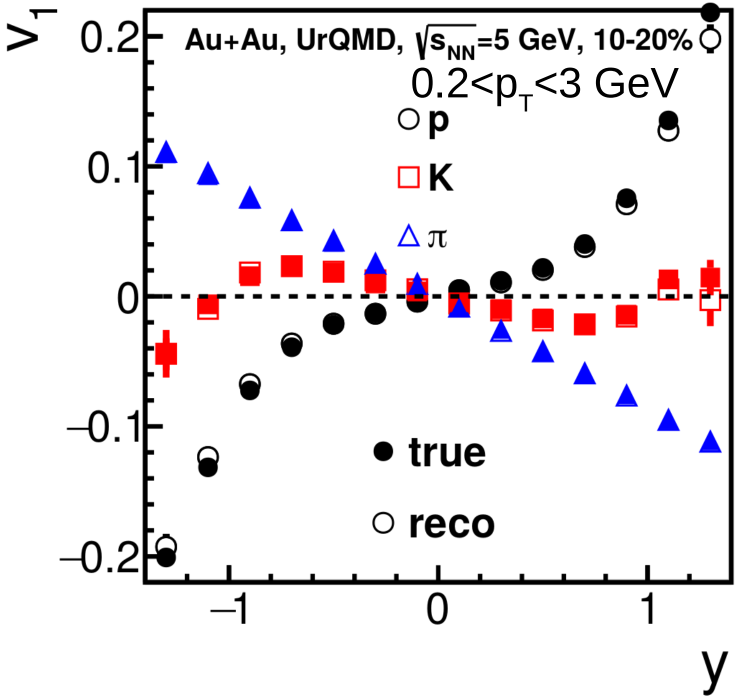
Resolution correction factor: GEANT3 vs GEANT4 comparison

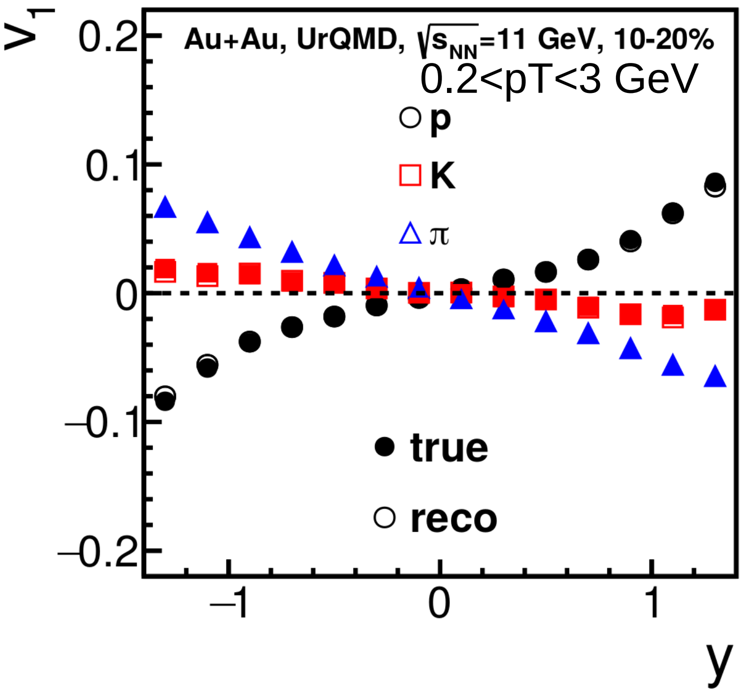




GEANT4 has more realistic hadronic shower simulation

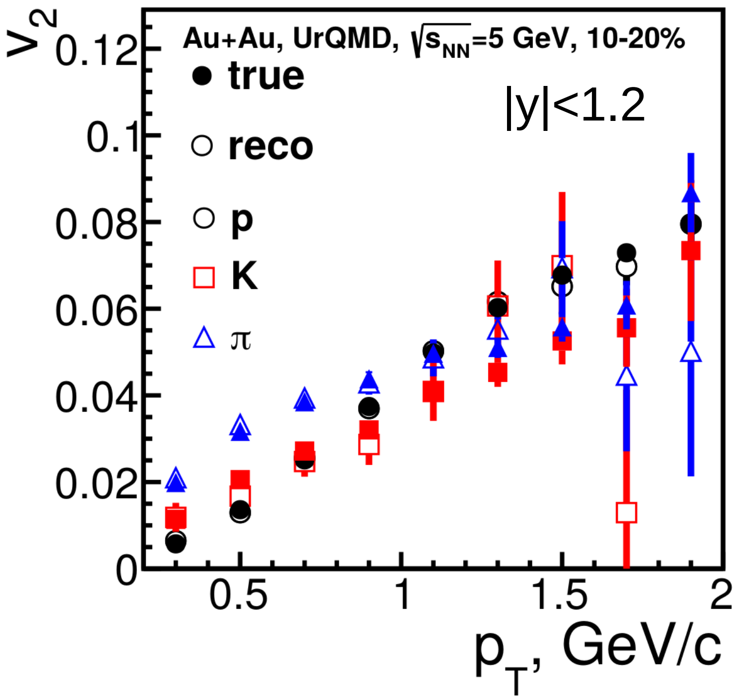
y-distribution of the directed flow

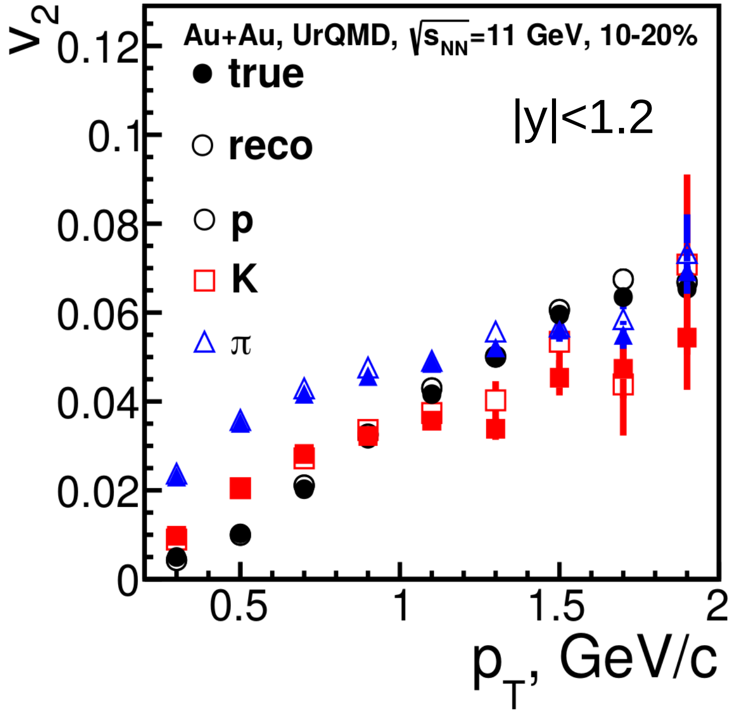




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

p_T-dependence of the elliptic flow





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

Model comparison

Data set

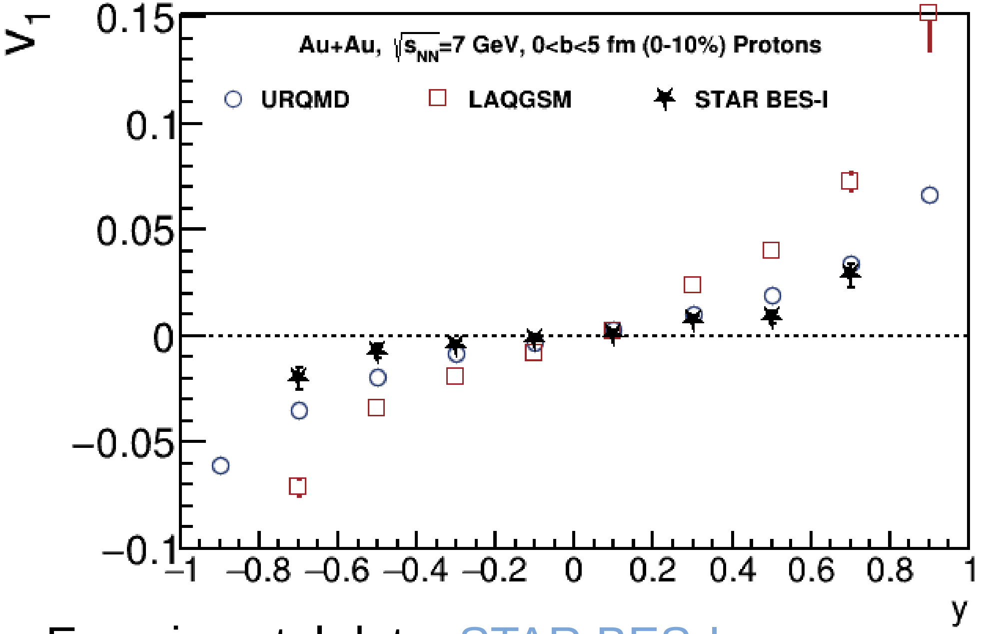
Simulated data:

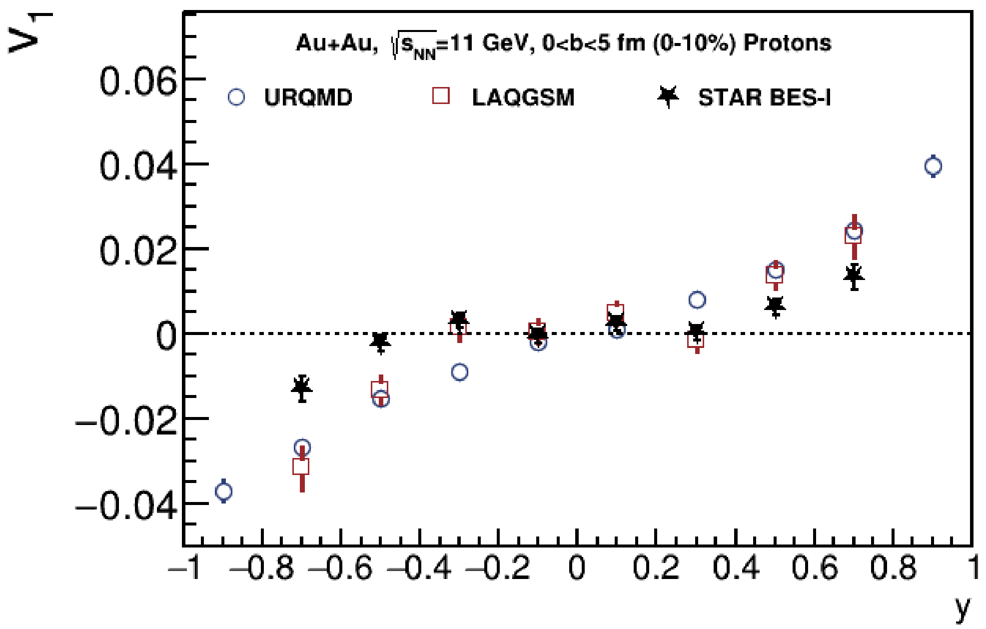
- UrQMD, Au+Au, $\sqrt{s_{NN}}$=11.5 GeV, 1M events
- LAQGSM, Au+Au, $\sqrt{s_{NN}}$=11 GeV, 100k events

- UrQMD, Au+Au, $\sqrt{s_{NN}}$=7.7 GeV, 1M events
- LAQGSM, Au+Au, $\sqrt{s_{NN}}$=7 GeV, 100k events

Event (centrality) selected regions:
Central: $0 < b < 5$ fm
Midcentral: $5 < b < 9$ fm (in backup)
Peripheral: $9 < b < 15$ fm (in backup)
taken from:
Phys.Rev. C 74, 064908 (2006).

Directed flow for protons

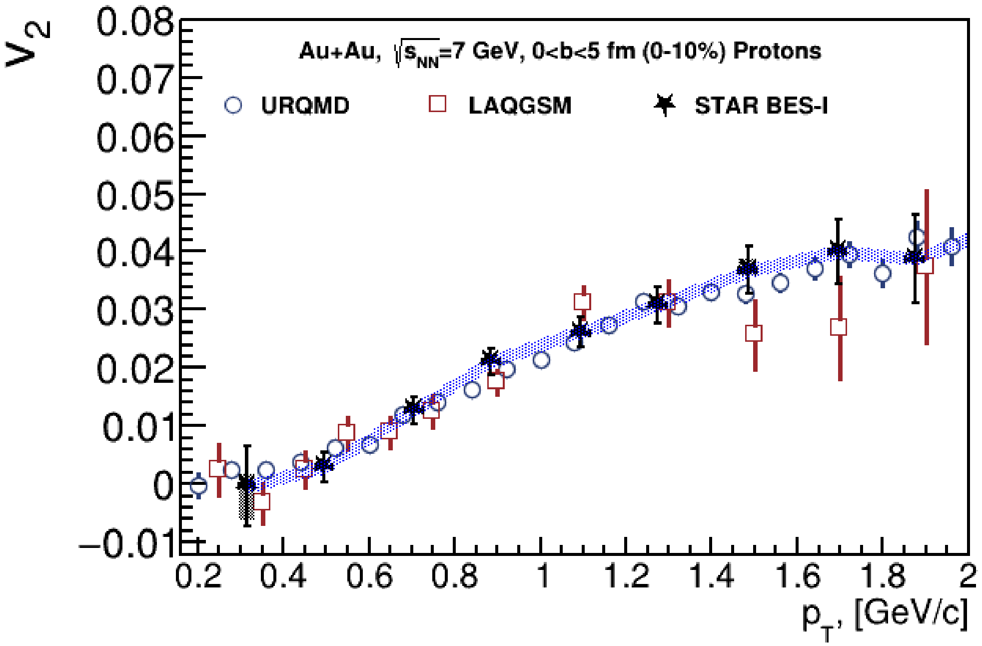


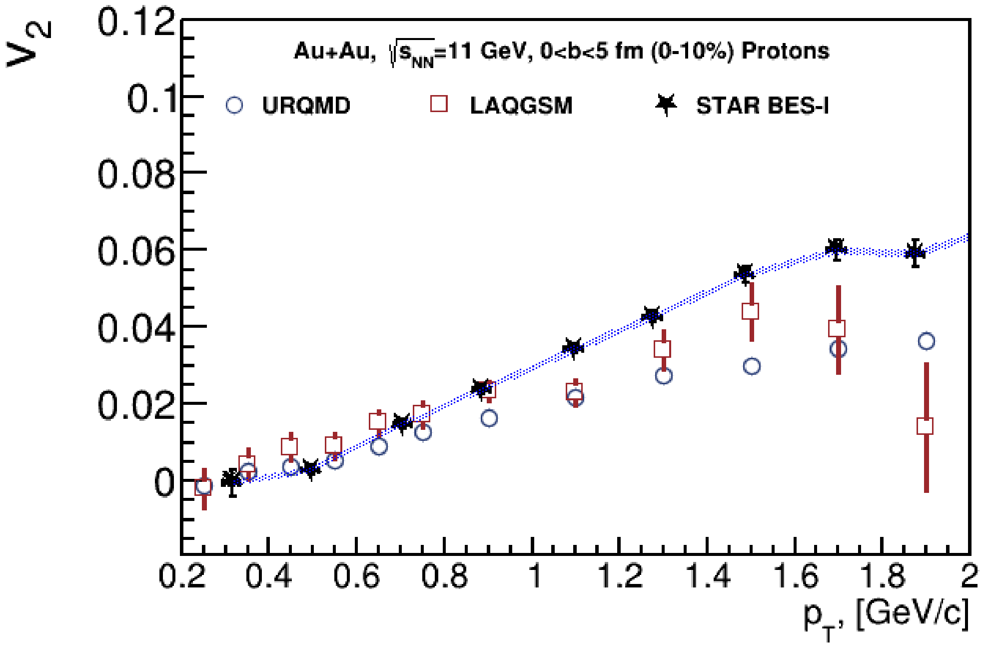


Experimental data: STAR BES-I

Better agreements: URQMD at 7 GeV, LAQGSM at 11 GeV

Elliptic flow for protons





Experimental data: STAR BES-I

- statistical error - systematic error - global systematic error

Summary

Centrality determination:

- Procedure for centrality determination using multiplicity from TPC or energy deposition from FHCal is developed:
  - Centrality classification using TPC allows for impact parameter resolution 5-10%
  - Combined centrality estimation based on both TPC and FHCal is under development

Anisotropic flow performance:

- 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 simulated values

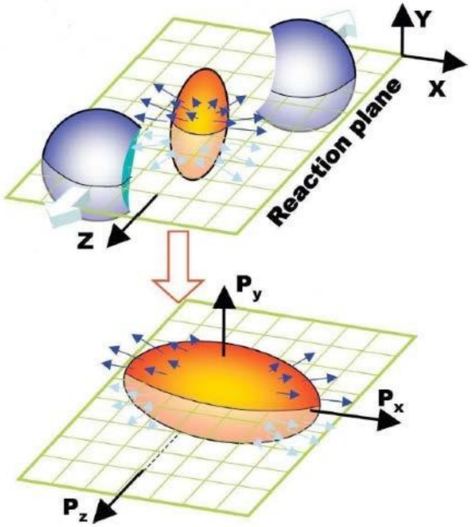
Model comparison:

- URQMD and LAQGSM predictions shows difference with the STAR data for both energies. Thorough comparison of all available models at all NICA energy range is required.

Thank you for your attention

Backup

Anisotropic azimuthal flow in heavy-ion collisions



Space anisotropy

Momenta anisotropy

$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos[n(\varphi-\Psi_n^{RP})]\right)$$

$$v_n\equiv\langle\cos[n(\varphi-\Psi_n^{RP})]\rangle$$

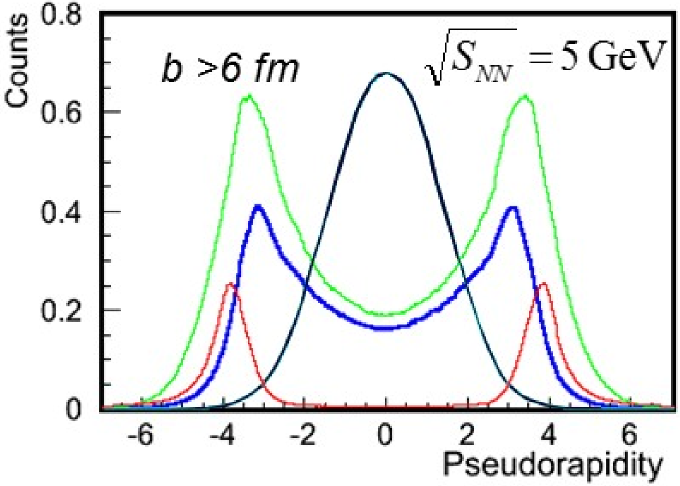
n-th harmonic with respect to *n-th* order reaction plane.

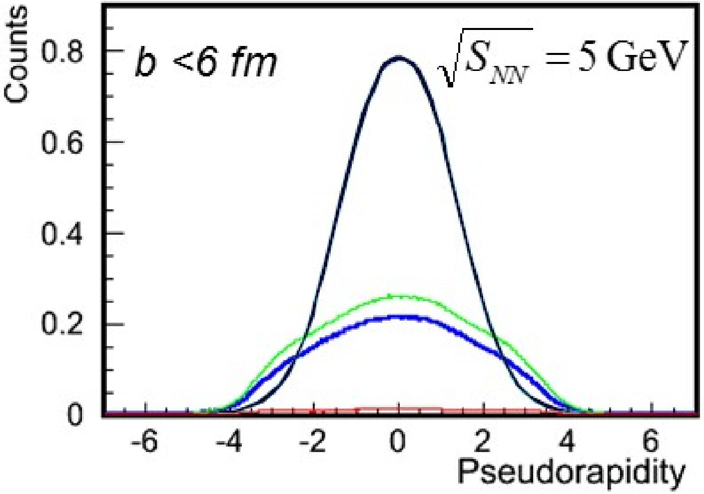
v_1 is called directed flow

v_2 is called elliptic flow

Initial geometry can be described with the distance between two nuclei and reaction plane orientation.

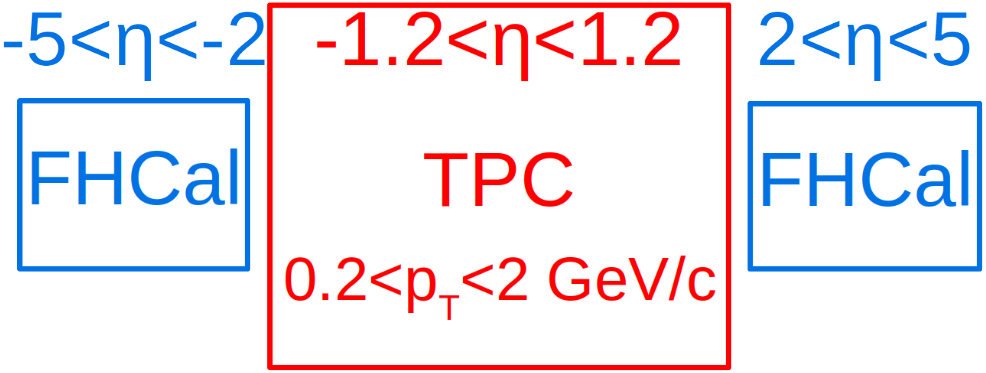
FHCal and TPC acceptance



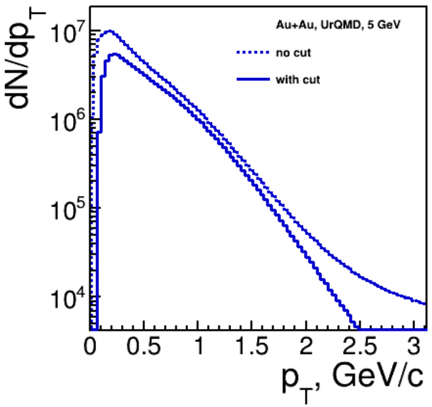


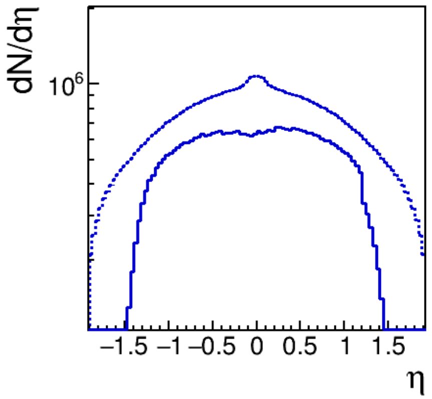
Pions
Neutrons
Protons
Fragments

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

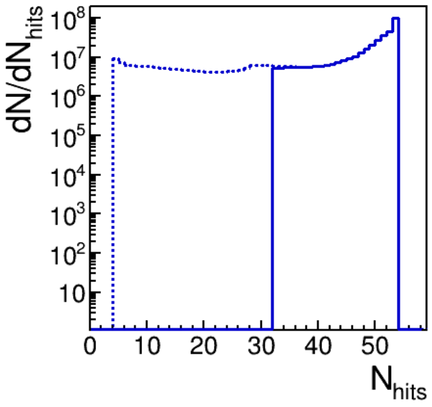


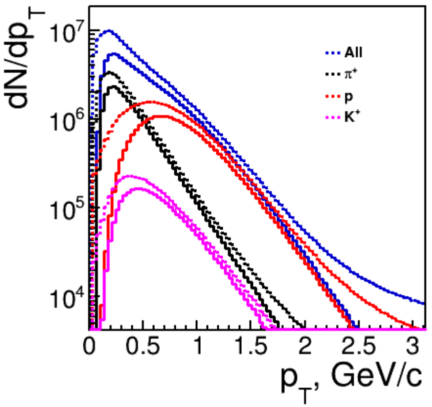
Track selection

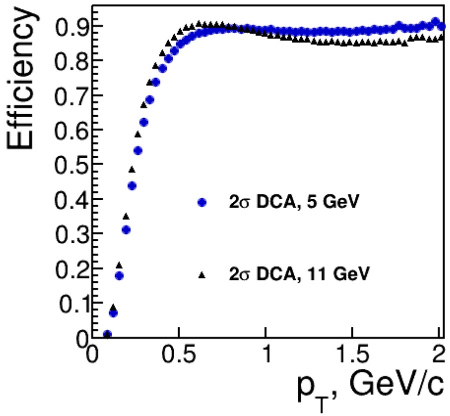




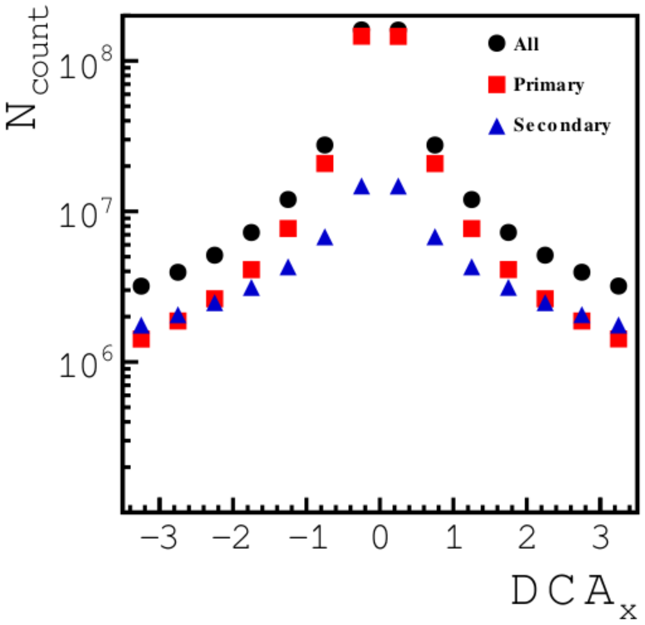
- $N_{TPC\ hits}$ >32
- $|p_T|$<3
- $|\eta|$<1.5
- PID based on TPC+TOF (MpdPid)

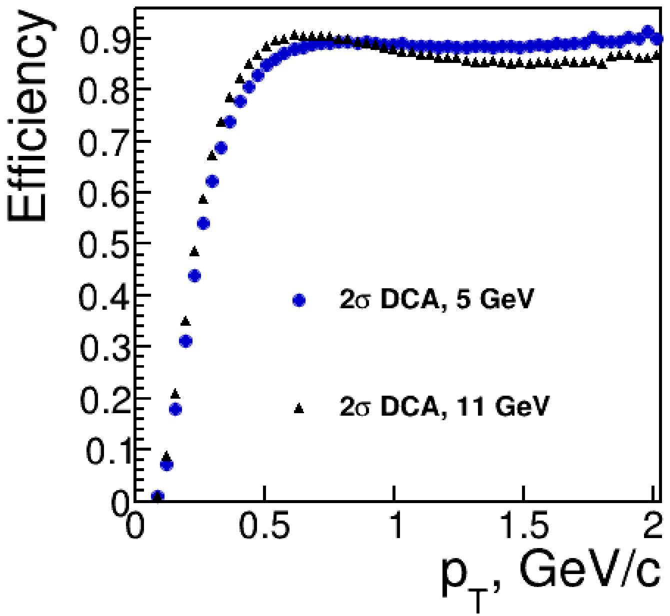






Primary track selection



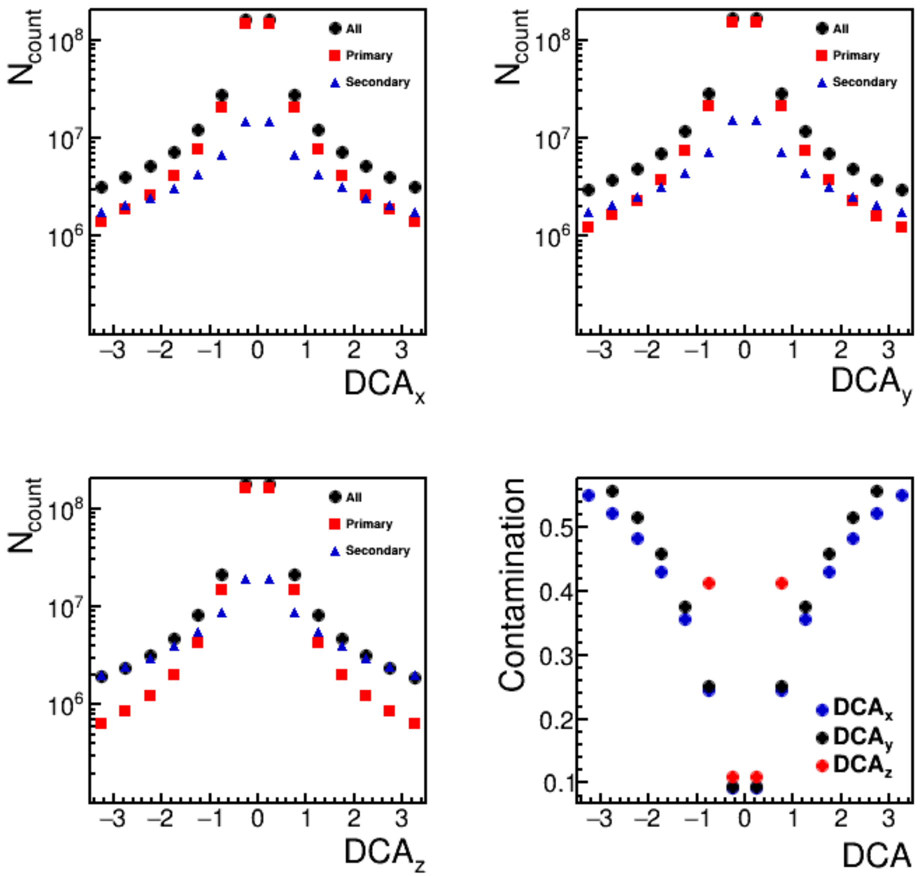


Distance of the closest approach (DCA) between TPC tracks and primary vertex

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

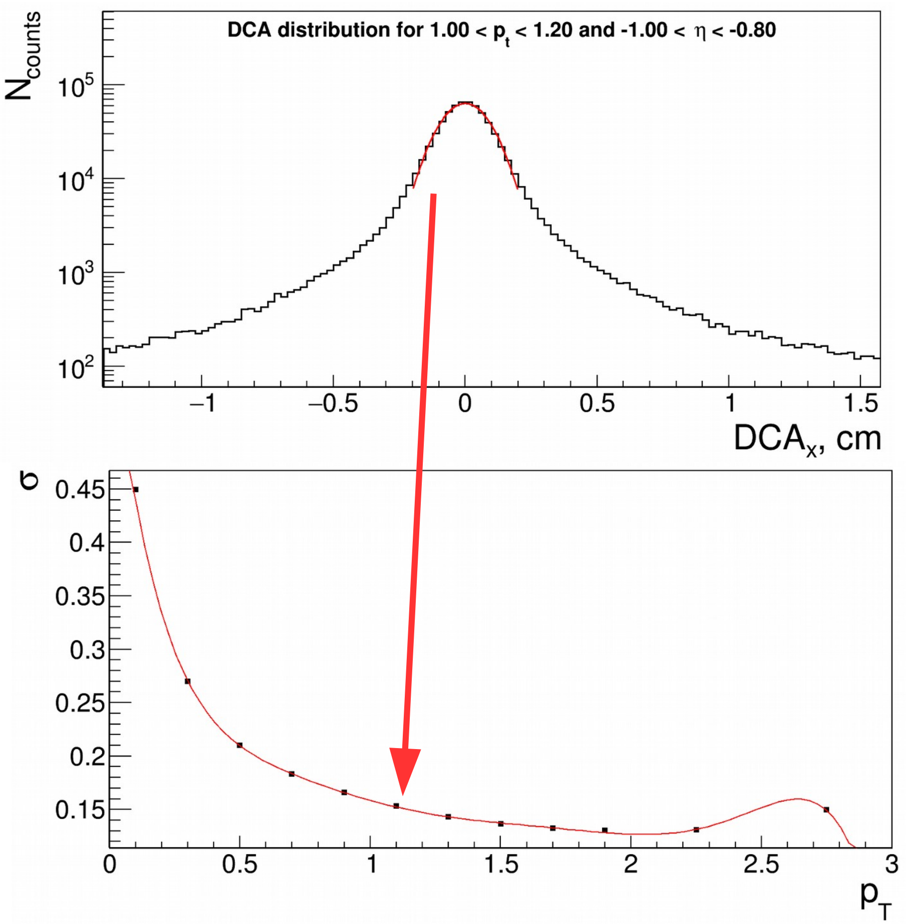


Distance of the closest approach (DCA) between TPC tracks and primary vertex

Tracks from secondary particles distort measured azimuthal flow coefficients

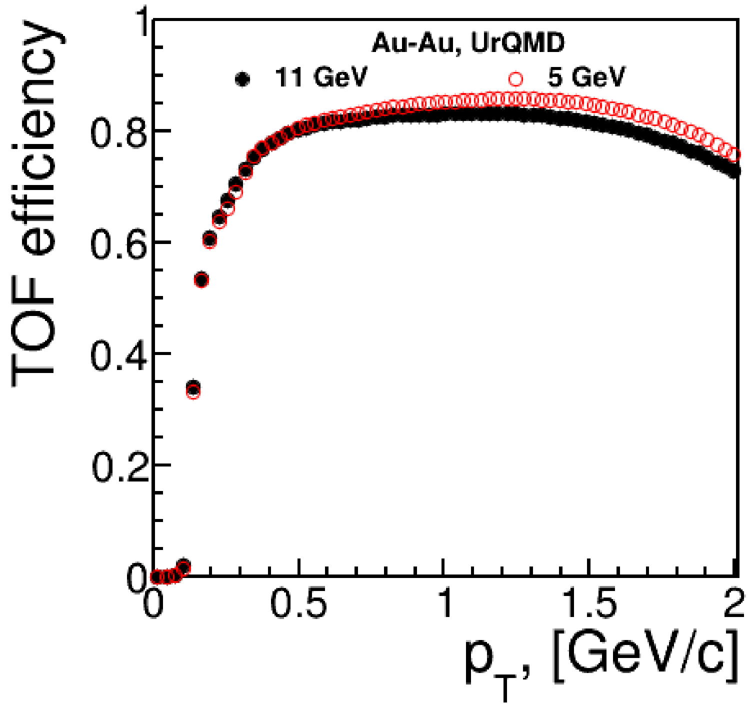
Introduced p T and η dependent 2σ DCA cut from Gaussian fit with smoothened p T dependence to reduce secondary contamination

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

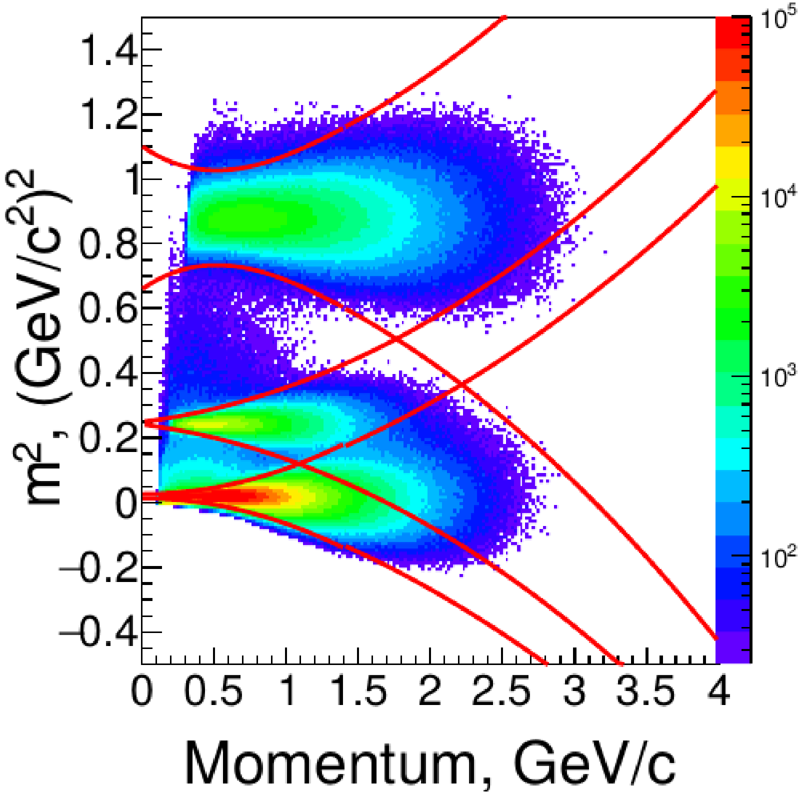


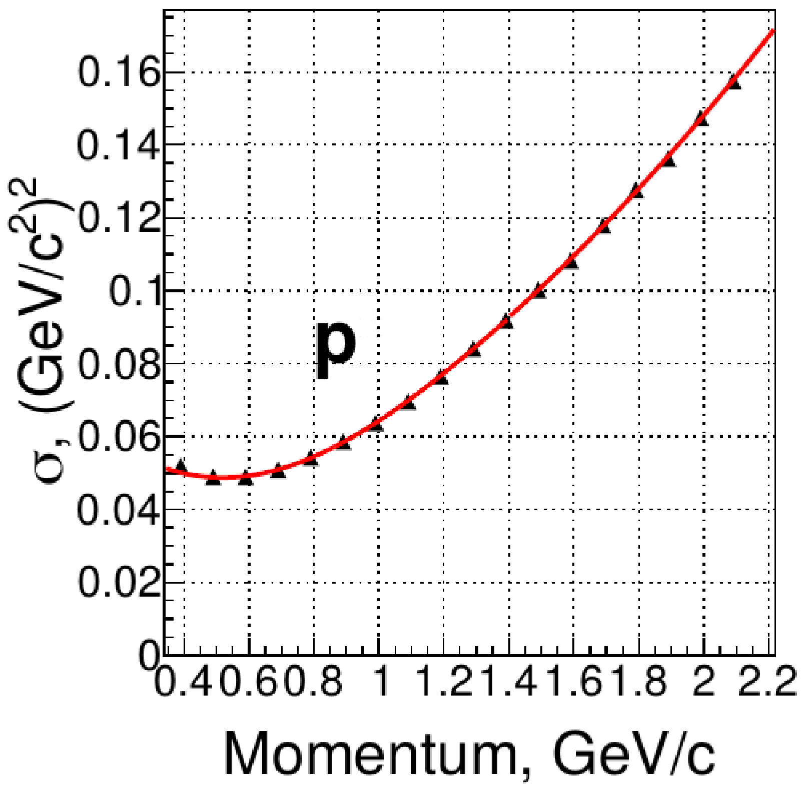
Only tracks with TOF hit were selected

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

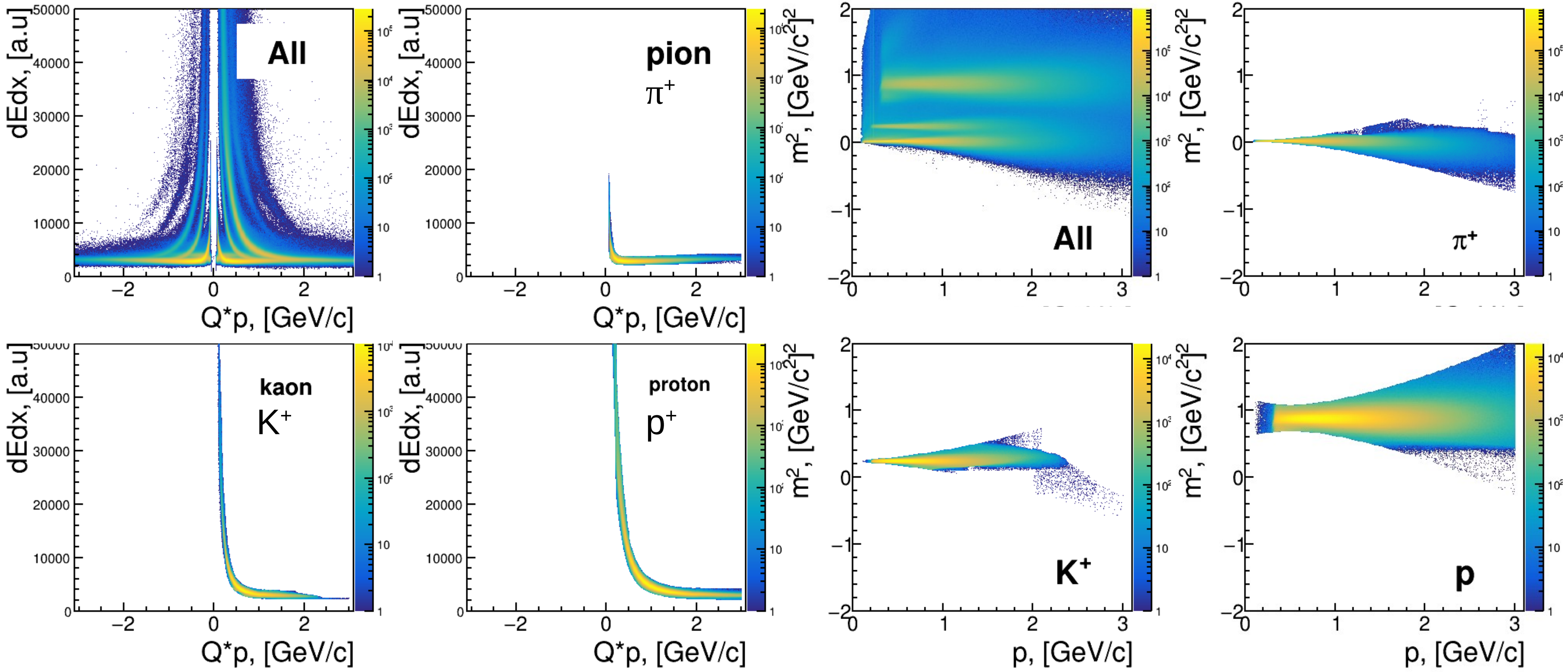




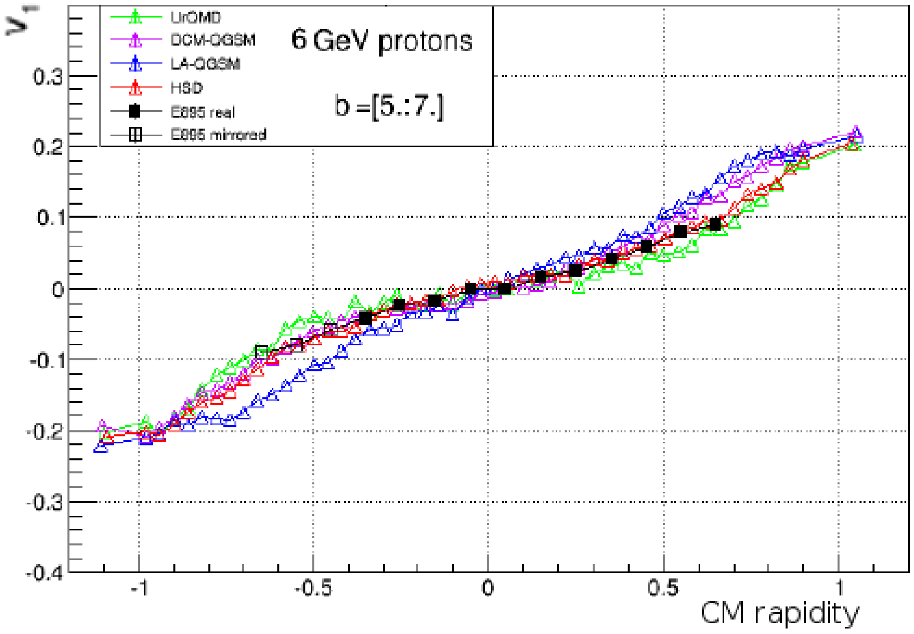
TOF identification significantly improves PID results in the high momenta region (p>1 GeV/c). It is based on the separation by the m^2 values.

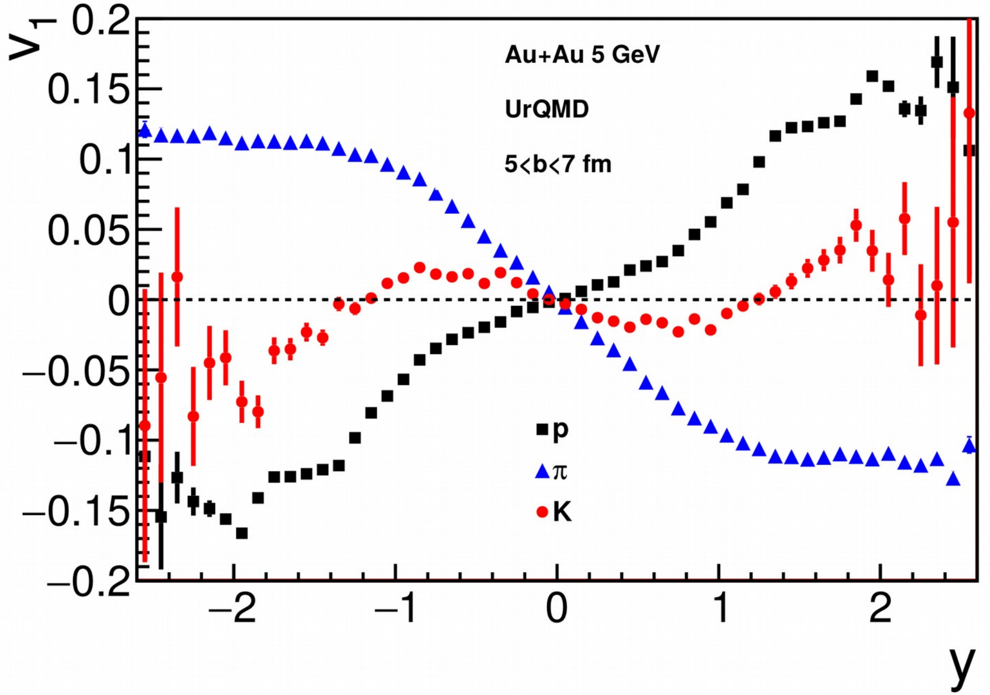
Red lines on this figure show 3σ bands for pions, kaons and protons.

PID implementation in the performance study



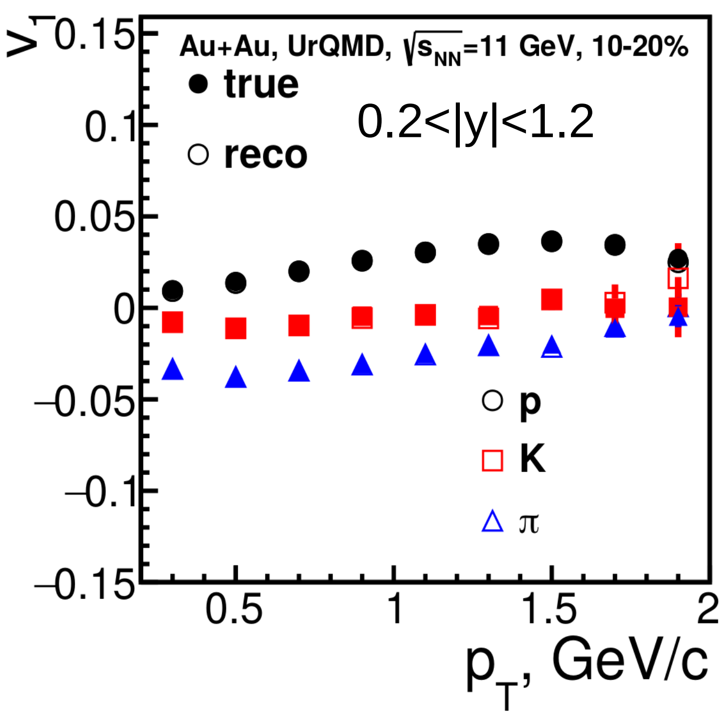
Modeling directed flow at NICA energies

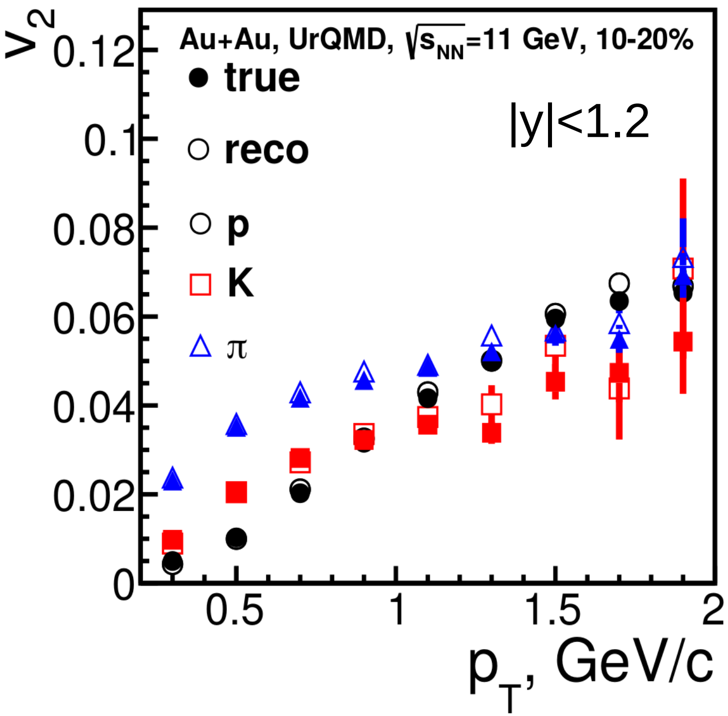




Both UrQMD and LAQGSM are in agreement with experimental measurements.
For performance study UrQMD and LAQGSM are used.

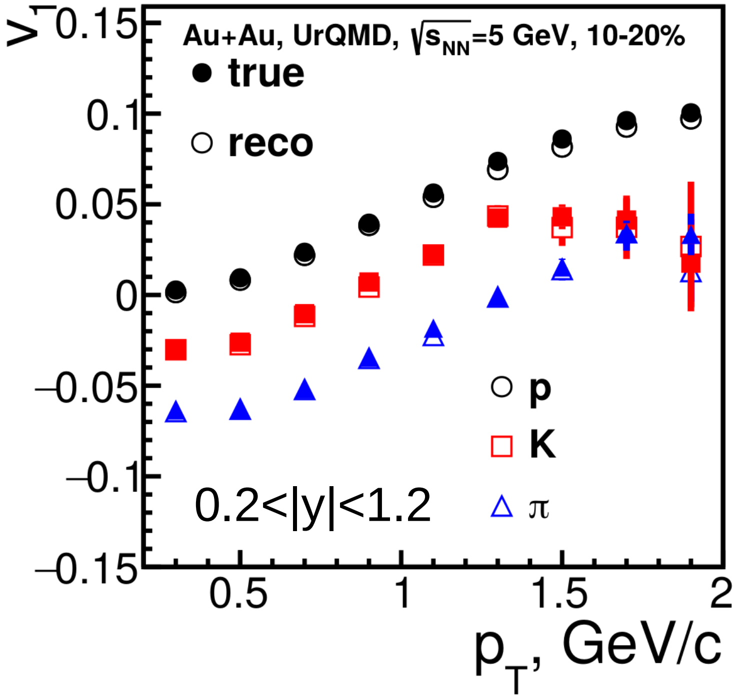
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

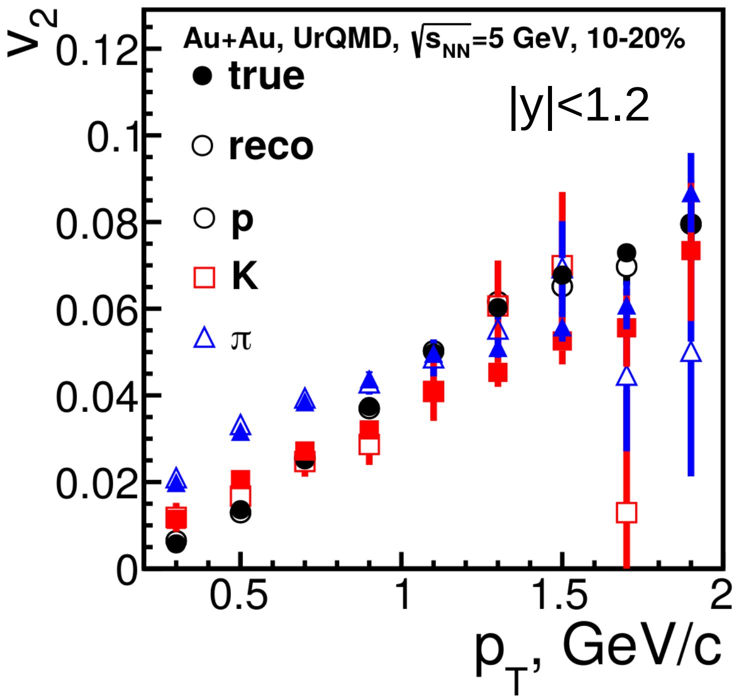




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

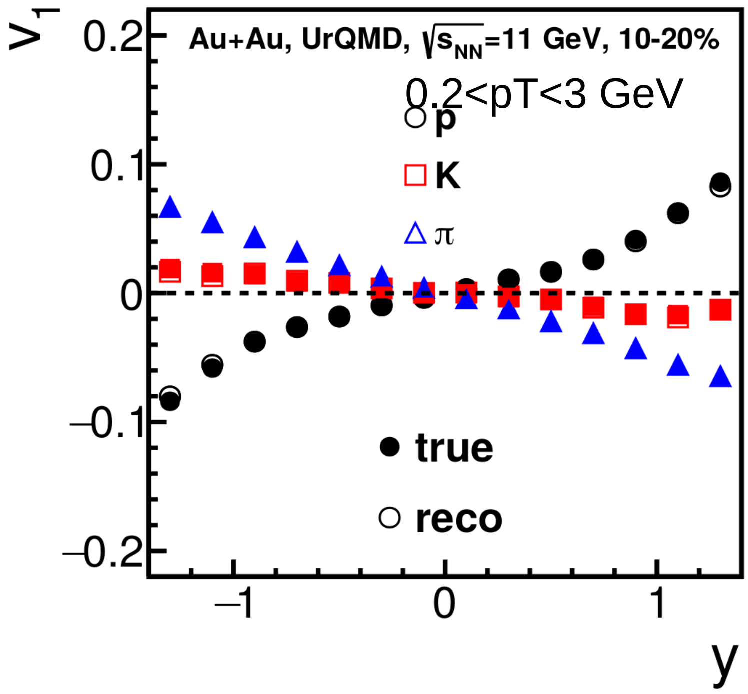
$v_{1,2}$ (p_T), Au+Au, $\sqrt{s_{NN}}$ = 5 GeV

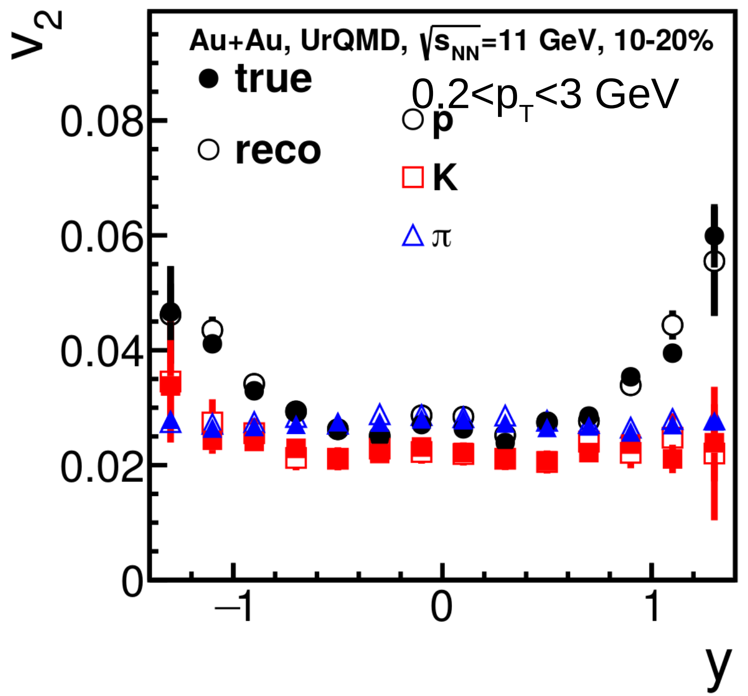




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

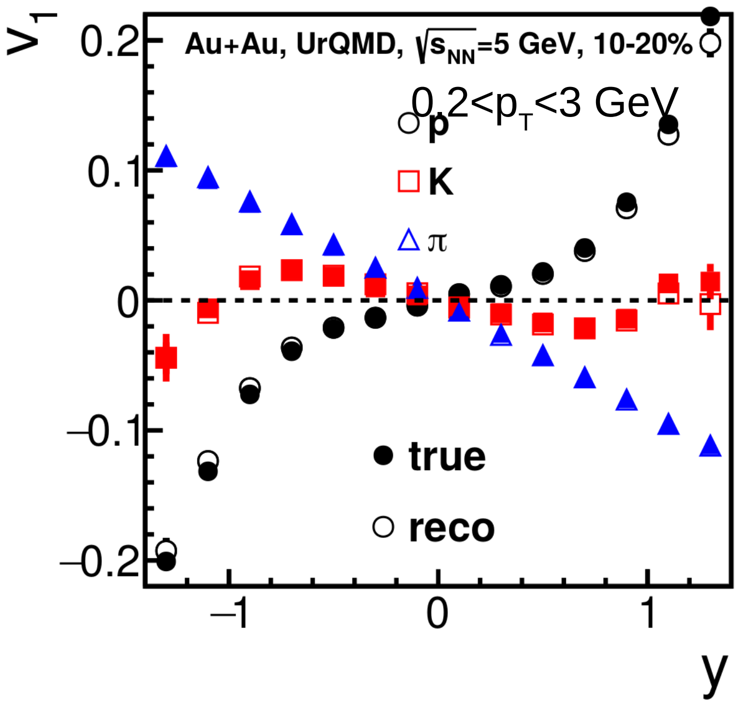
$v_{1,2}$ (y), Au+Au, $\sqrt{s_{NN}}$ = 11 GeV

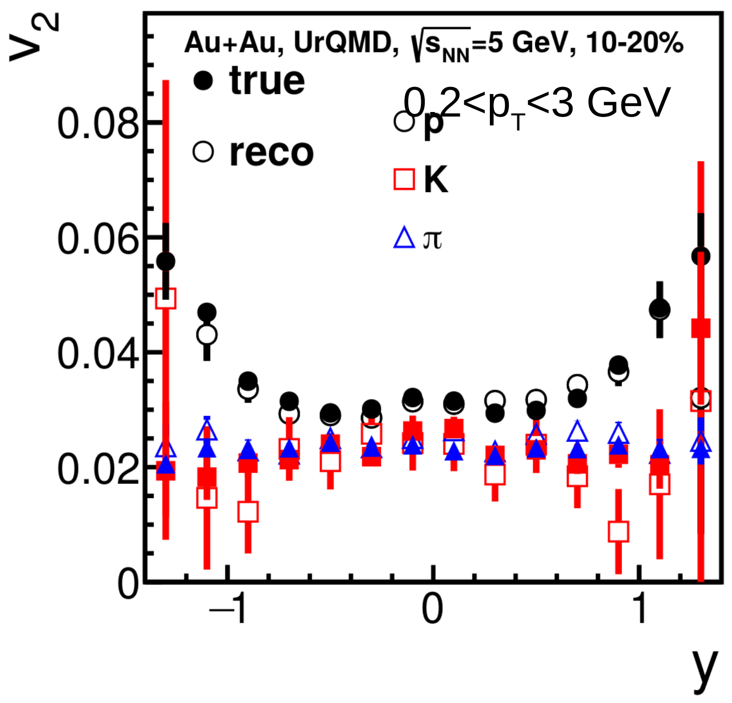




Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

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

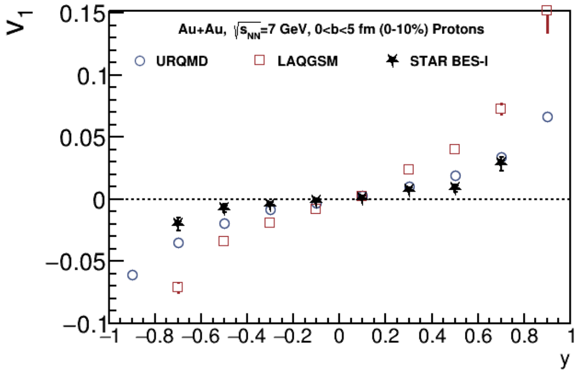


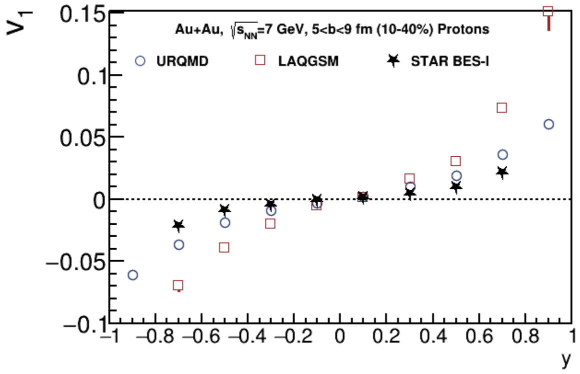


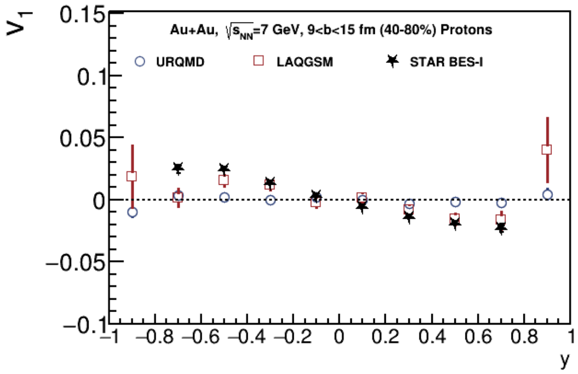
Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

7.7 GeV

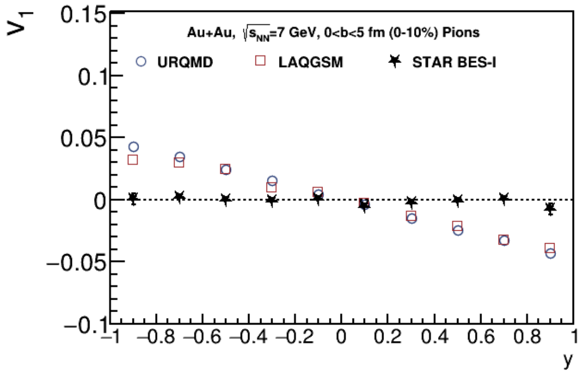
v_1 (y) for protons

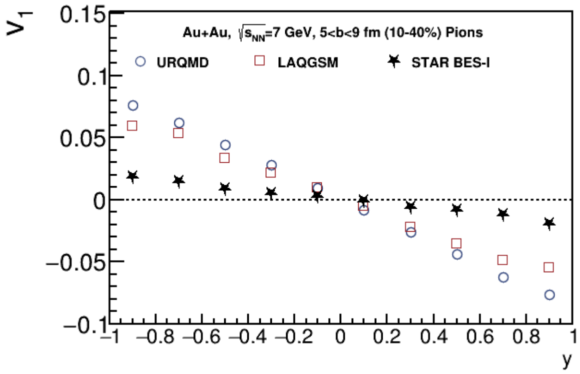


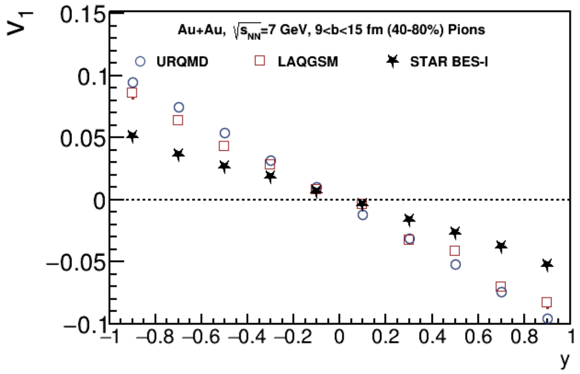




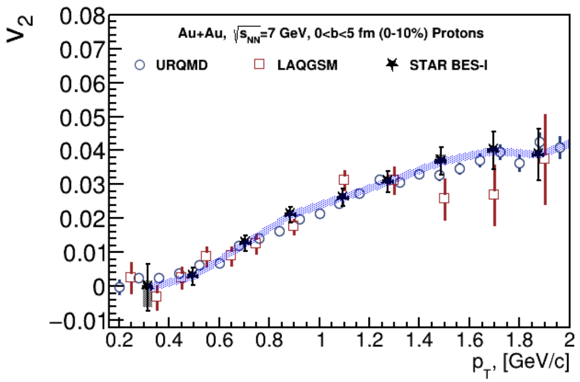
v_1 (y) for pions

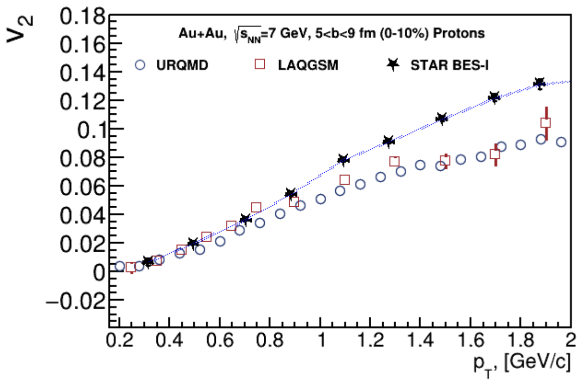


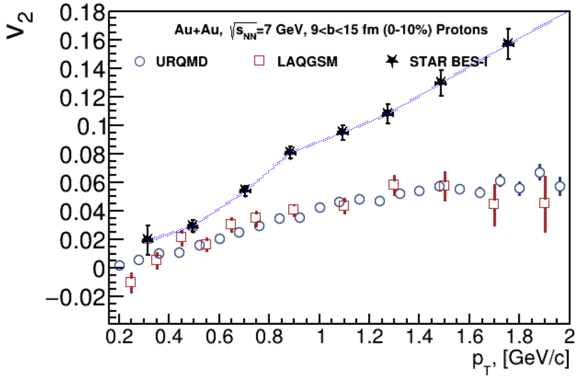




v_2 (p_T) for protons



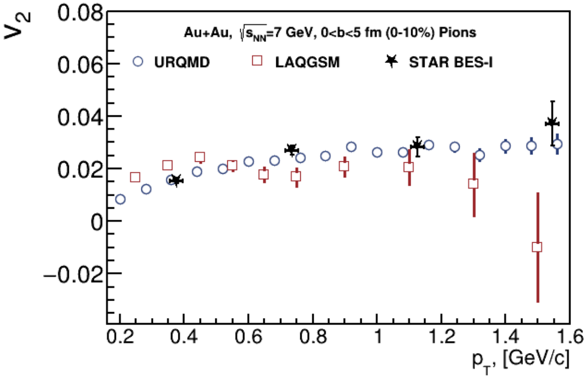


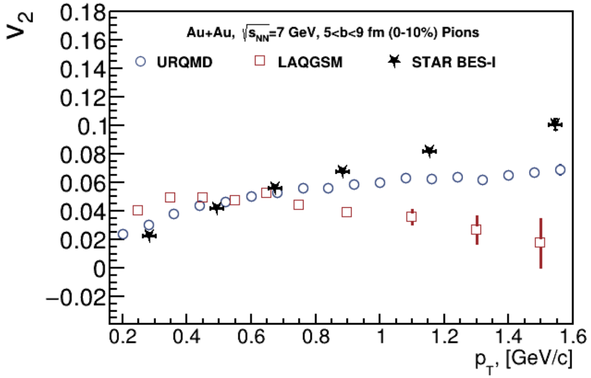


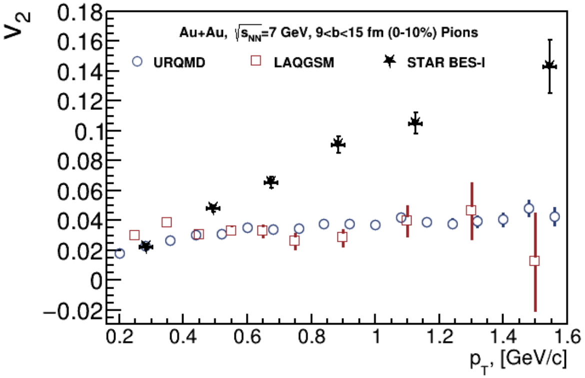
Experimental data: STAR BES-I

- statistical error
- systematic error
- global error

$v_2\,(p_T)$ for pions







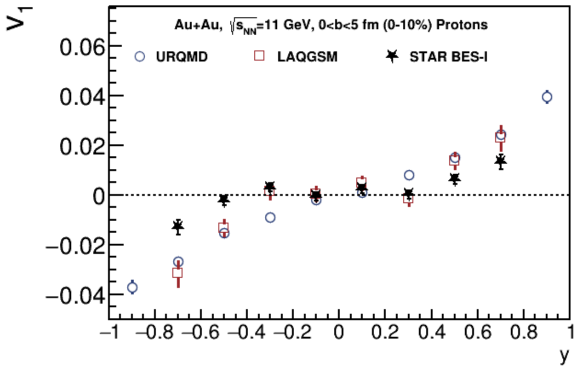
Experimental data: STAR BES-I

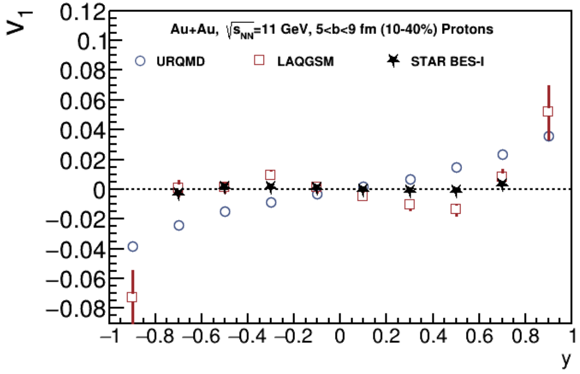
I - statistical error

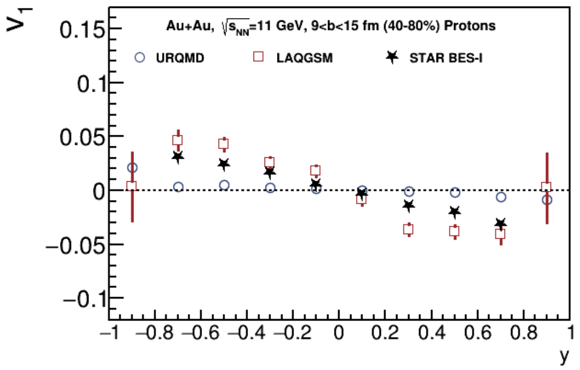
- systematic error

11.5 GeV

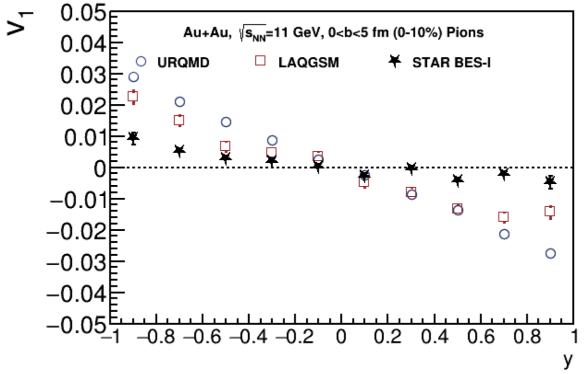
v_1 (y) for protons

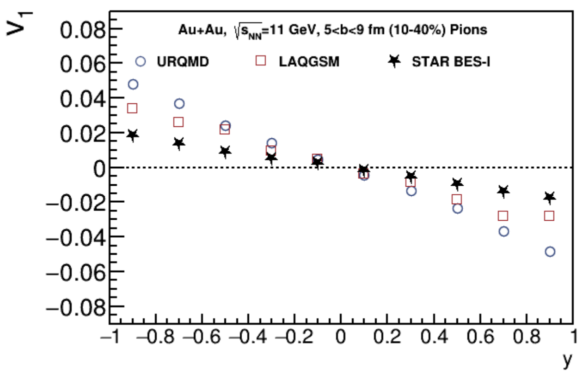


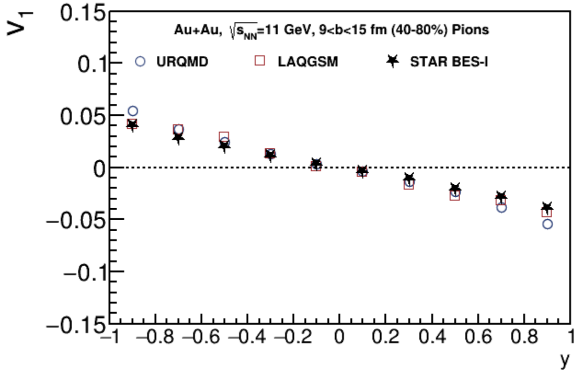




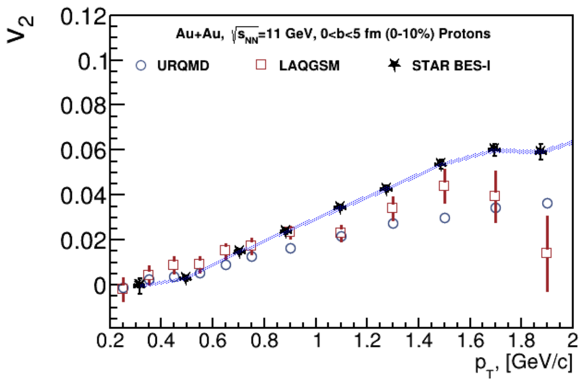
$v_1(y)$ for pions

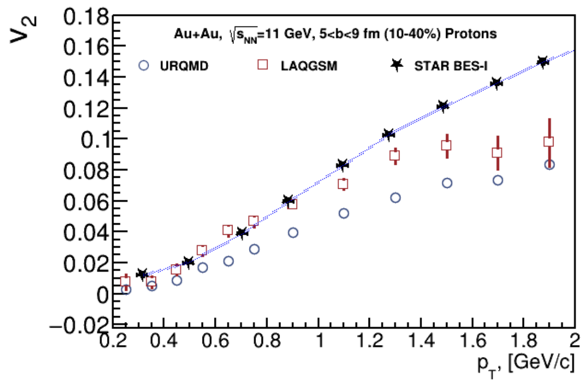


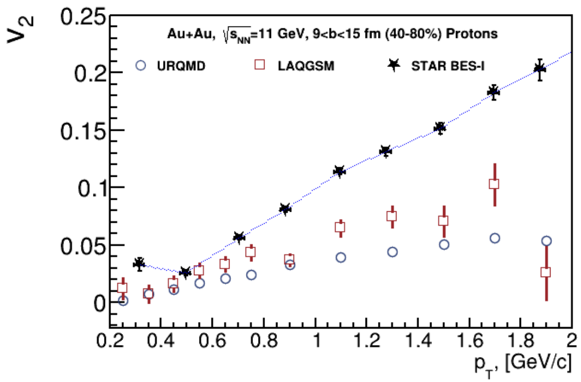




$v_2(p_T)$ for protons



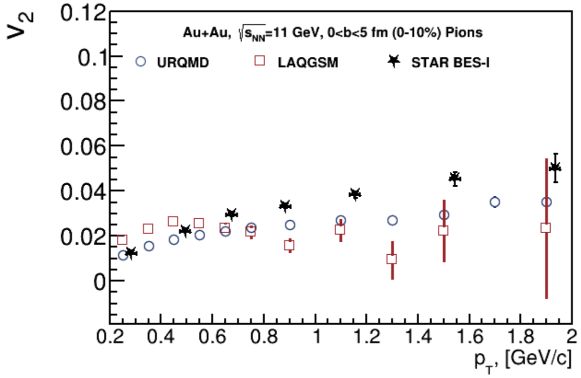


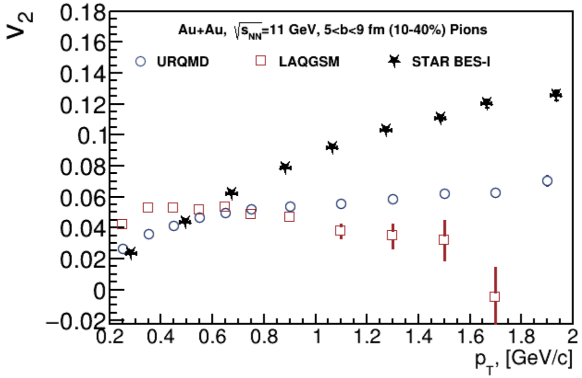


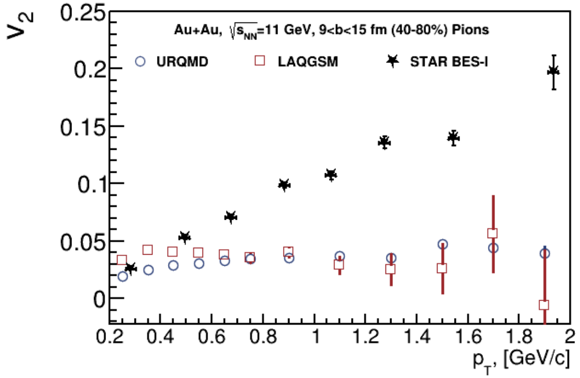
Experimental data: STAR BES-I

- statistical error
- systematic error
- global error

v_2 (p_T) for pions







Experimental data: STAR BES-I

I - statistical error

▒ - systematic error