Anisotropic Flow measurements with MPD detector at NICA

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NICA(JINR), Dubna, Russia

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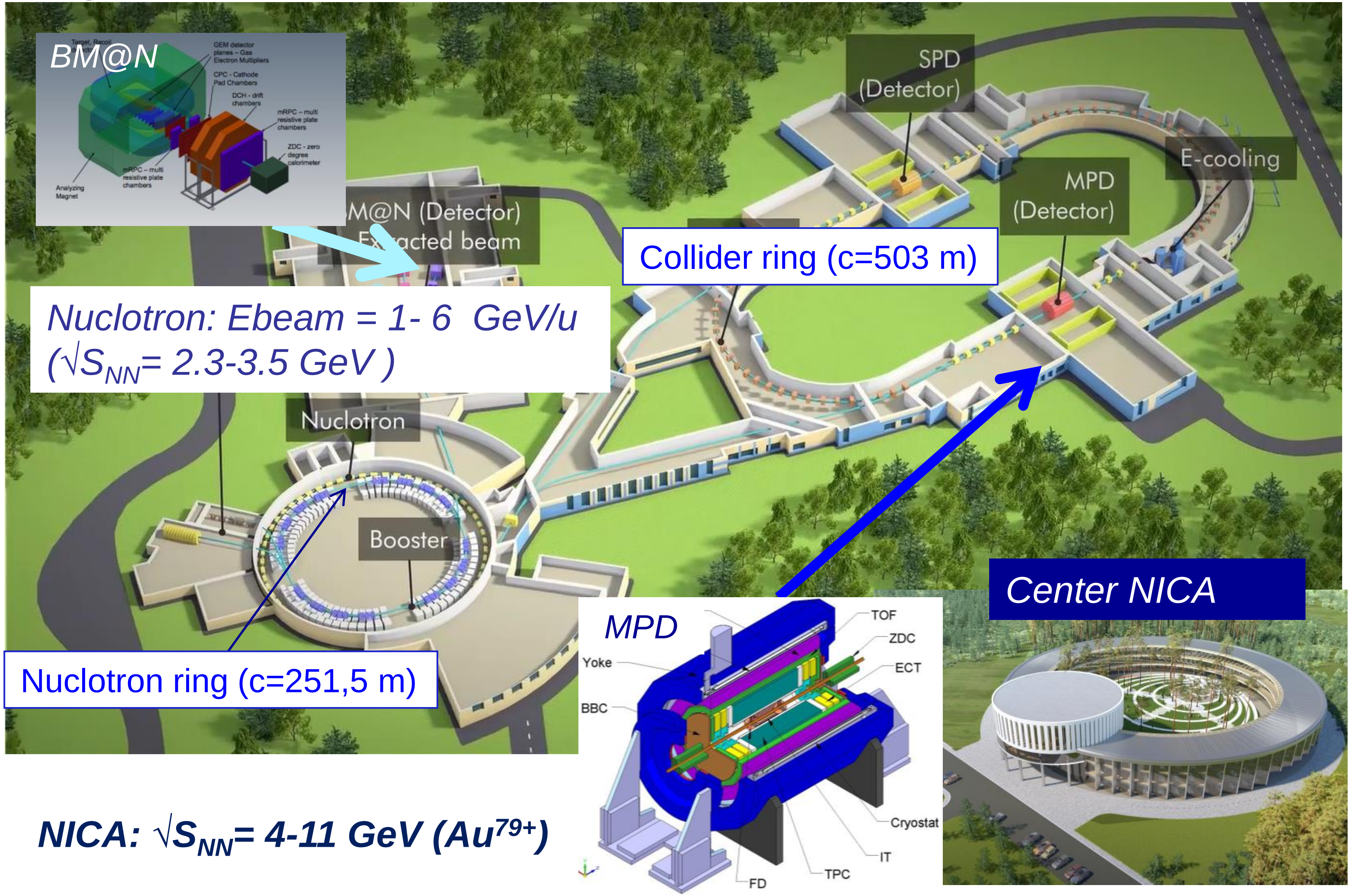


Collider ring (c=503 m)

Nuclotron: Ebeam = 1- 6 GeV/u
($\sqrt{S_{NN}}$= 2.3-3.5 GeV)

Nuclotron ring (c=251,5 m)

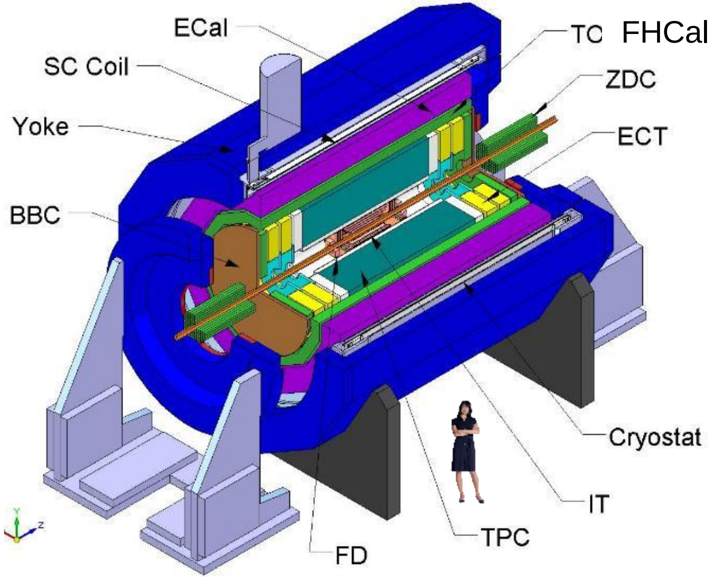
NICA: $\sqrt{S_{NN}}$= 4-11 GeV (Au^{79+})

August 2020

NICA

MPD collaboration

11 countries, ***38*** *institutes*, ***505*** *scientists*



IHEP, Beijing, ***China****;*
University of South China, ***China****;*
Palacky University, Olomouc, ***Czech Republic****;*
NPI CAS, Rez, ***Czech Republic****;*
Tbilisi State University, Tbilisi, ***Georgia****;*
Tubingen University, Tubingen, ***Germany****;*
Tel Aviv University, Tel Aviv, ***Israel****;*
Joint Institute for Nuclear Research;
IPT, Almaty, ***Kazakhstan****;*
Consortium MEXNICA, ***Mexico****;*
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WUT, Warsaw, ***Poland****;*
NCN, Otwock – Swierk, ***Poland****;*
UW, Wroclaw, ***Poland****;*
Jan Kochanowski University, Kielce, ***Poland****;*
INR RAS, Moscow, ***Russia****;*
NRNU MEPhI, Moscow, Russia;
*PNPI, Gatchina****, Russia****;*
INP MSU, Moscow, ***Russia;***
KI NRS, Moscow, ***Russia****;*
SPSU - Dept. of NP, ***Russia;***
St. Petersburg, ***Russia****;*
SPSU – Dept. of HEP, St. Petersburg, ***Russia****;*
North Ossetia State University, Vladikavkaz, ***Russia****;*

Baku State University, NNRC, ***Azerbaijan****;*
University of Plovdiv, ***Bulgaria;***
University Tecnica Federico Santa Maria, Valparaiso, ***Chili****;*
Tsinghua University, Beijing, ***China****;*
USTC, Hefei, ***China****;*
Huizhou University, Huizhou, ***China****;*
Institute of Nuclear and Applied Physics, CAS, Shanghai, ***China****;*
Central China Normal University, ***China****;*
Shandong University, Shandong, ***China****;*

Anisotropic Flow in Heavy-Ion Collisions: 1988

Provides reliable estimates of pressure & pressure gradients

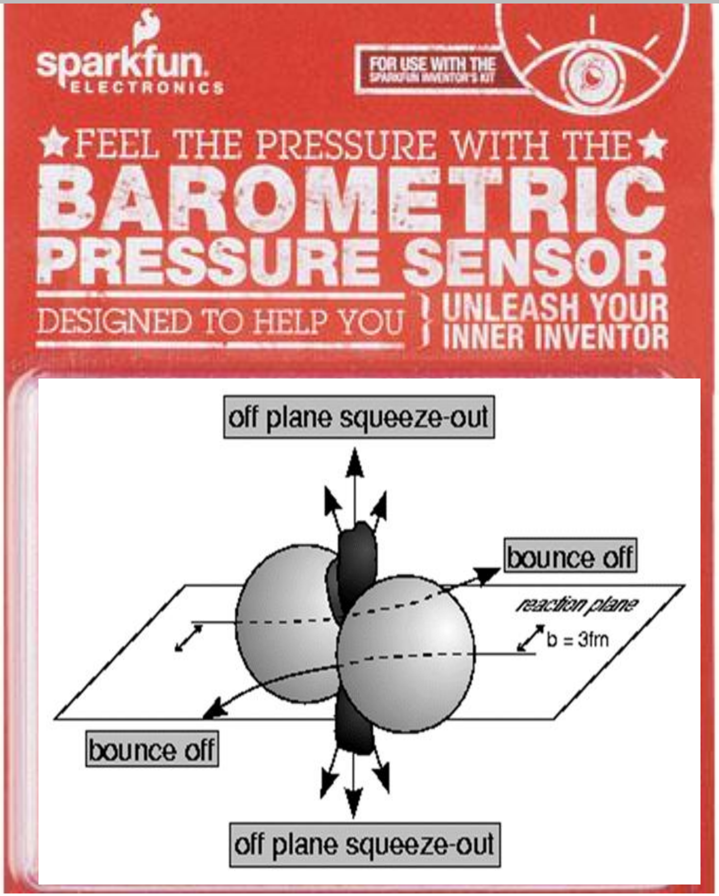
Can address questions related to thermalization

Gives insights on the transverse dynamics of the Medium

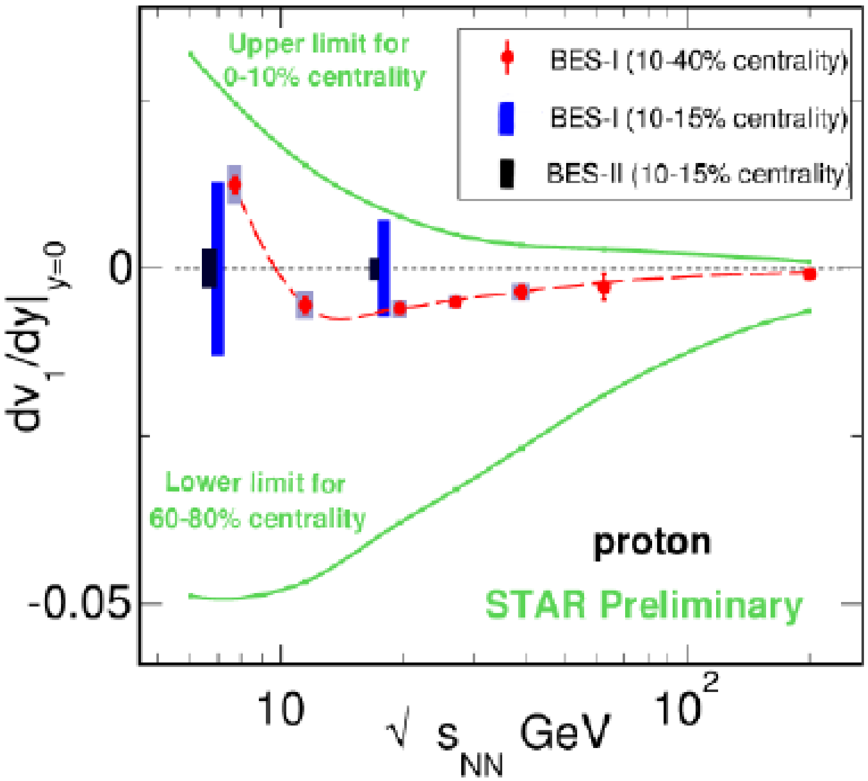
Provides access to the transport properties of the medium: EOS, sound speed (c_s), viscosity, etc

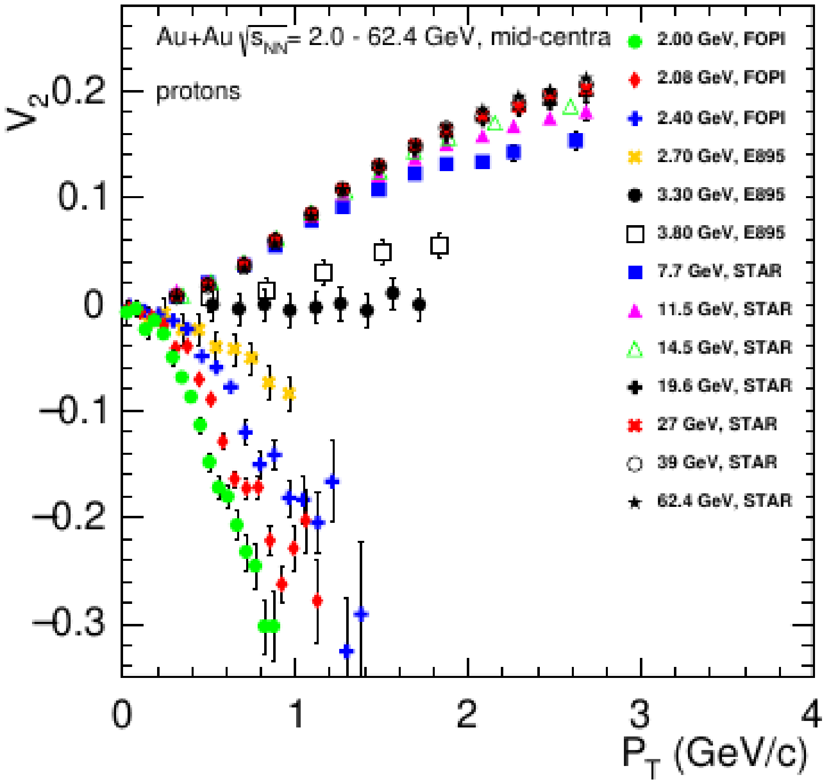
Plastic Ball Collaboration,
H.H. Gutbrod et al., Phys. Lett. B216, 267 (1989)

Fourier Expansion for azimuthal anisotropy,
Cheuk-Yin WONG, Physics Letters, 88B, p 39 (1979)



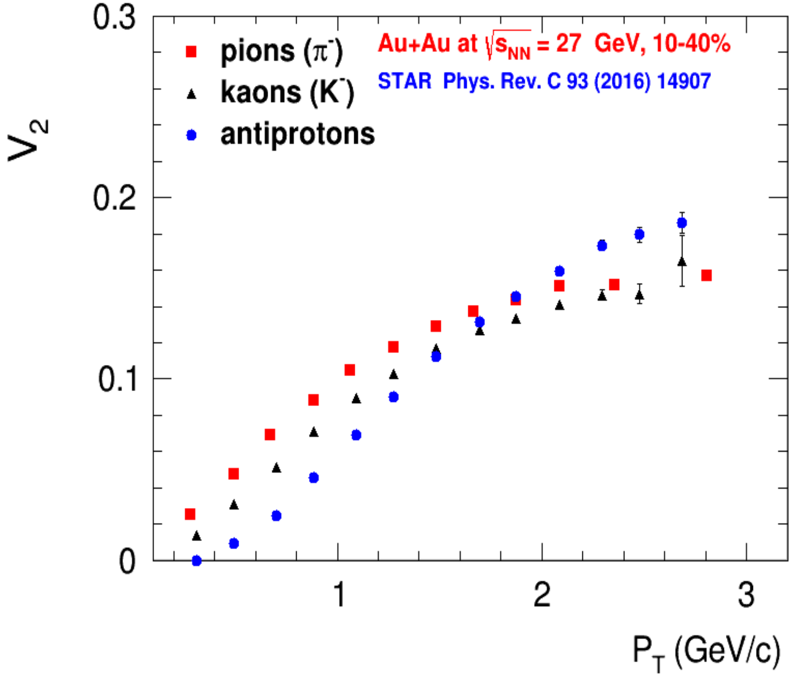
Anisotropic flow at NICA energies

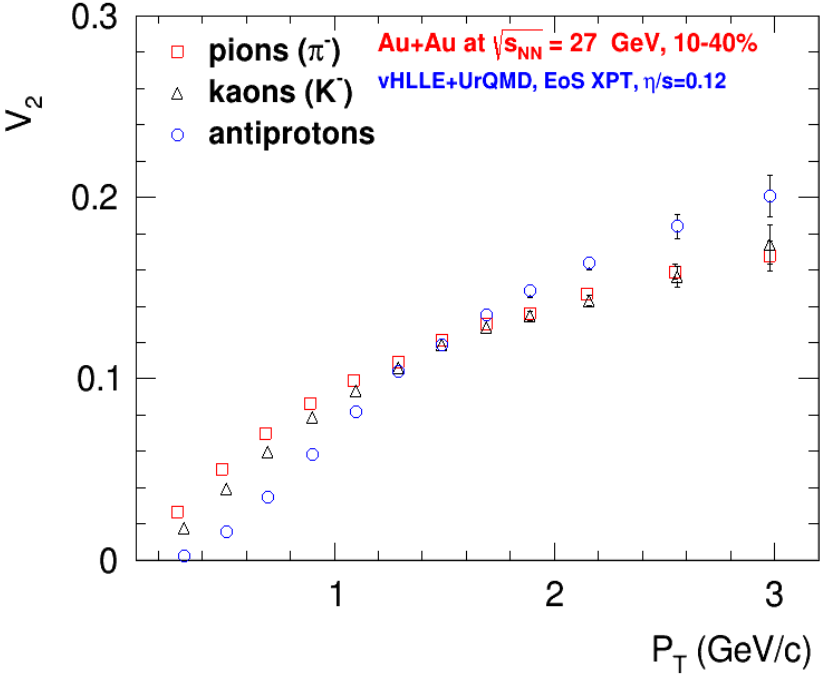




Anisotropic flow at NICA energies is a delicate balance between:
(i) the ability of pressure developed early in the reaction zone and
(ii) the passage time for removal of the shadowing by spectators

v_2 of identified hadrons at RHIC BES

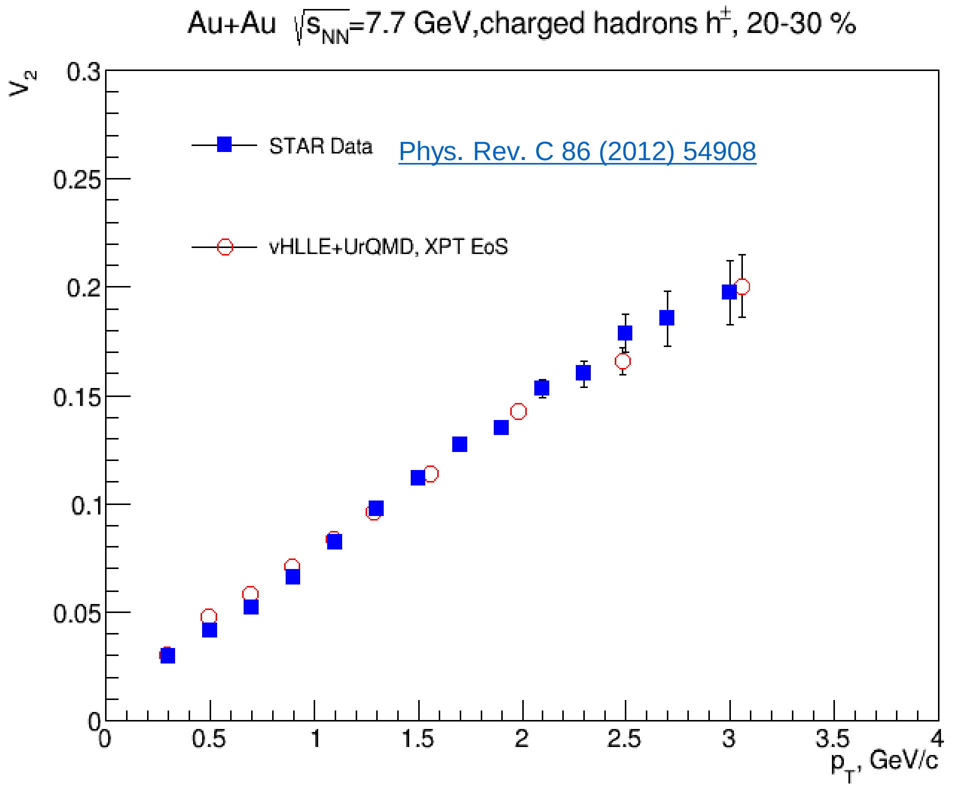


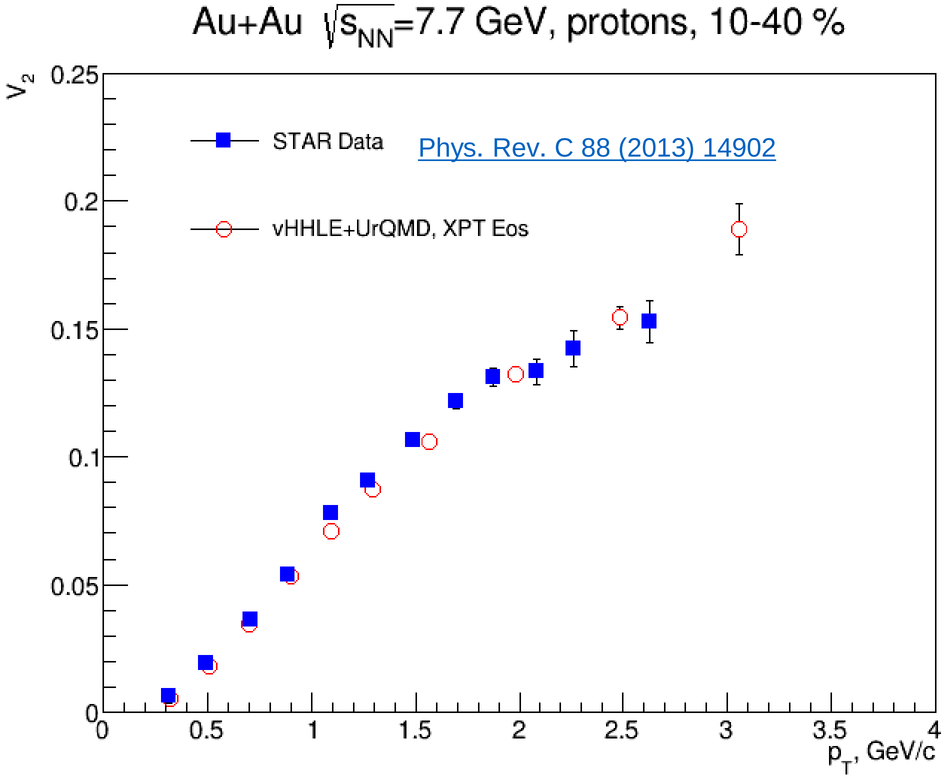


Mass ordering at p_T < 2 GeV/c (hydrodynamic flow, hadron re-scattering) : for heavy-particles the radial flow “blueshifts” the entire flow signal to higher p_T

Baryon/meson grouping at p_T > 2.5 GeV/c (recombination/coalescence),

Differential elliptic flow: 3D hydro vHLLE + UrQMD



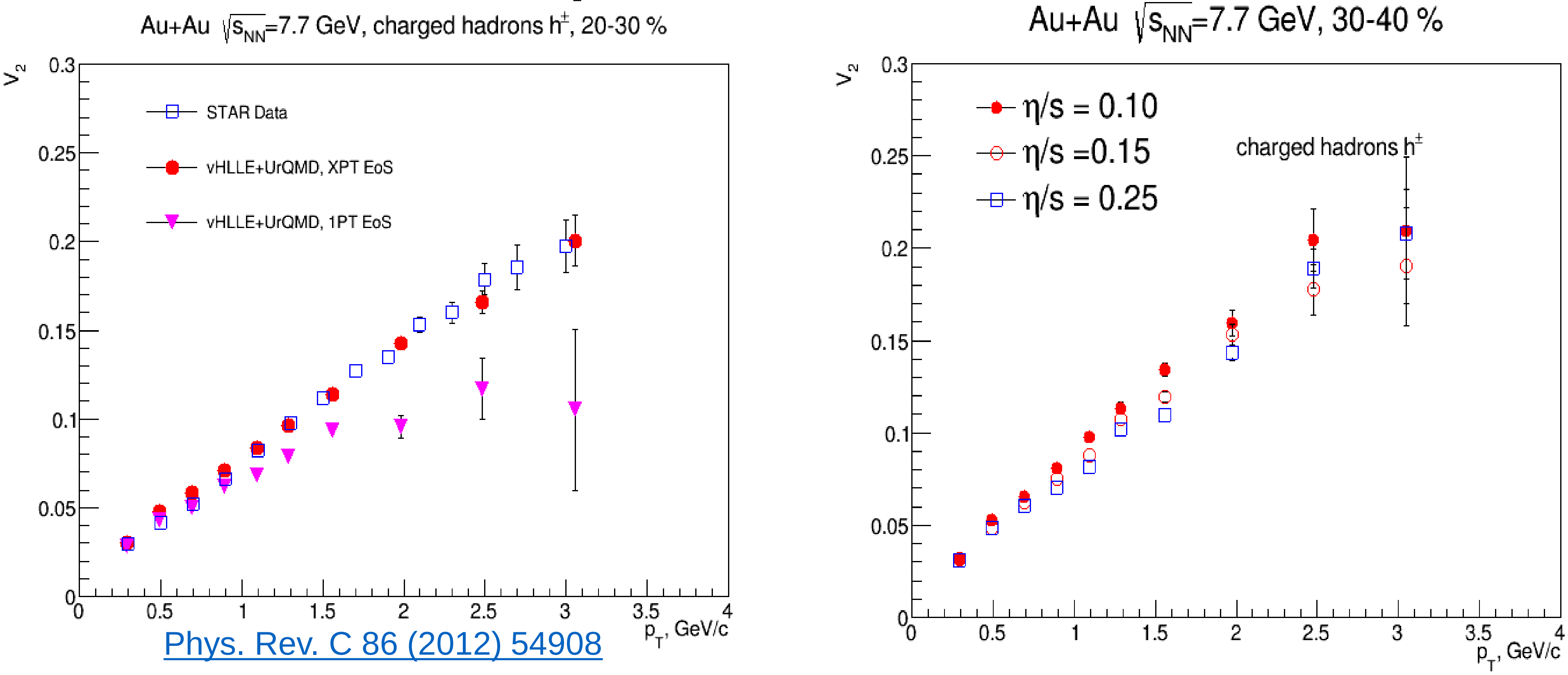


3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

Good agreement with STAR published data

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

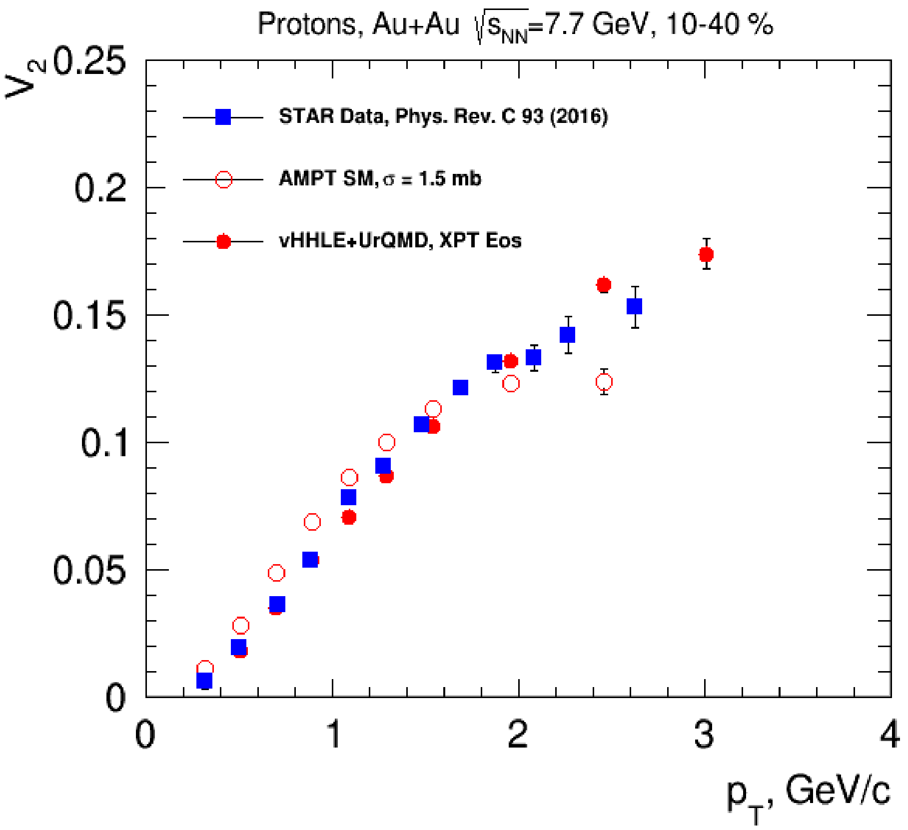
Differential elliptic flow: 3D hydro vHLLE + UrQMD

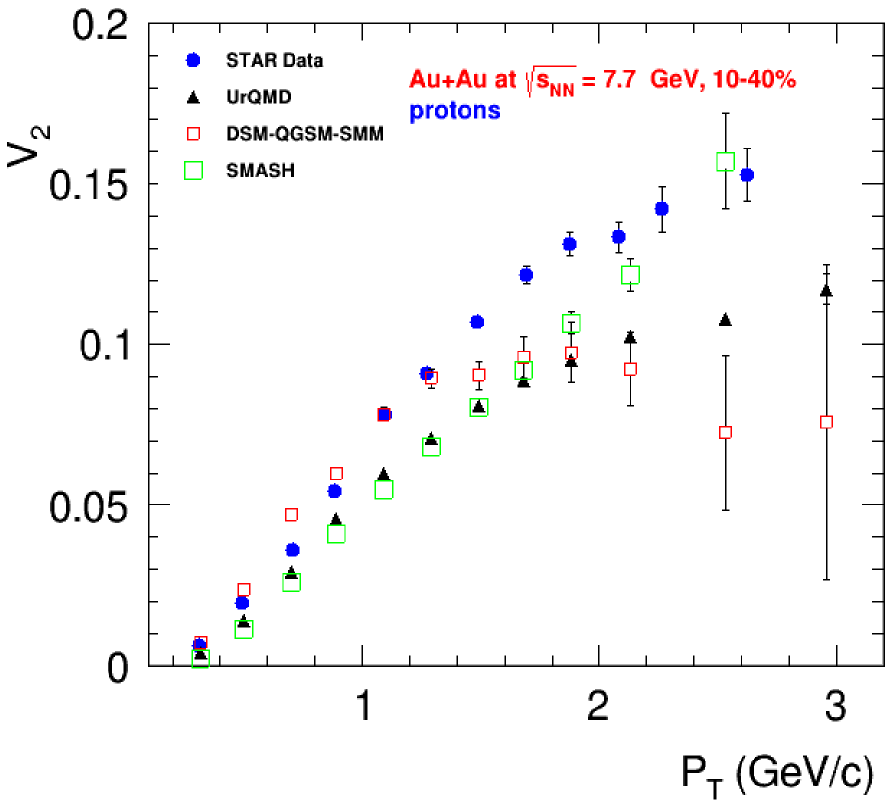


[Phys. Rev. C 86 (2012) 54908]

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

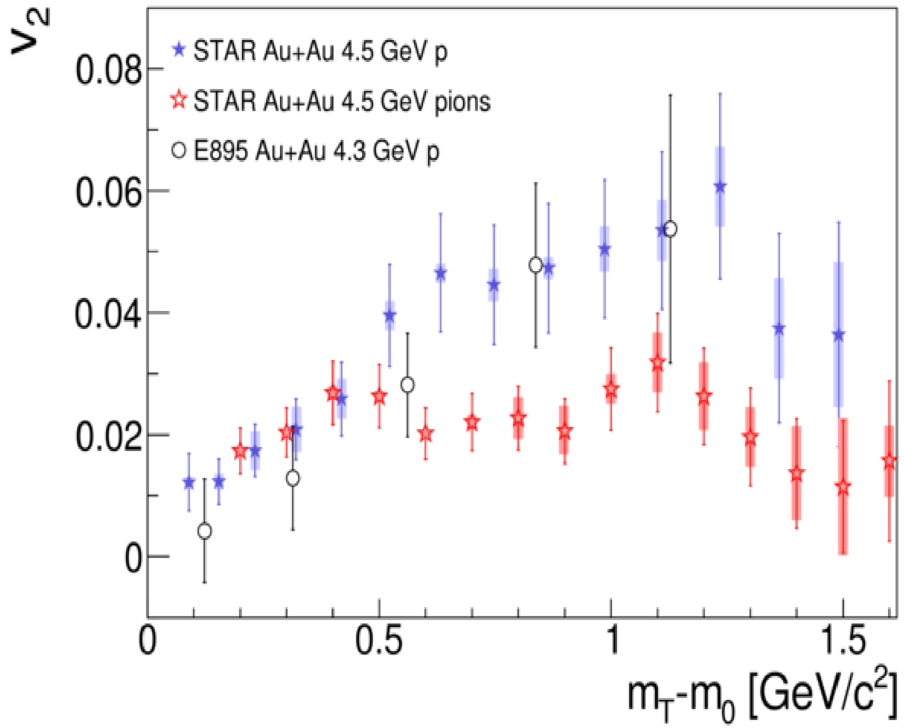
Elliptic flow: Models vs Data comparison

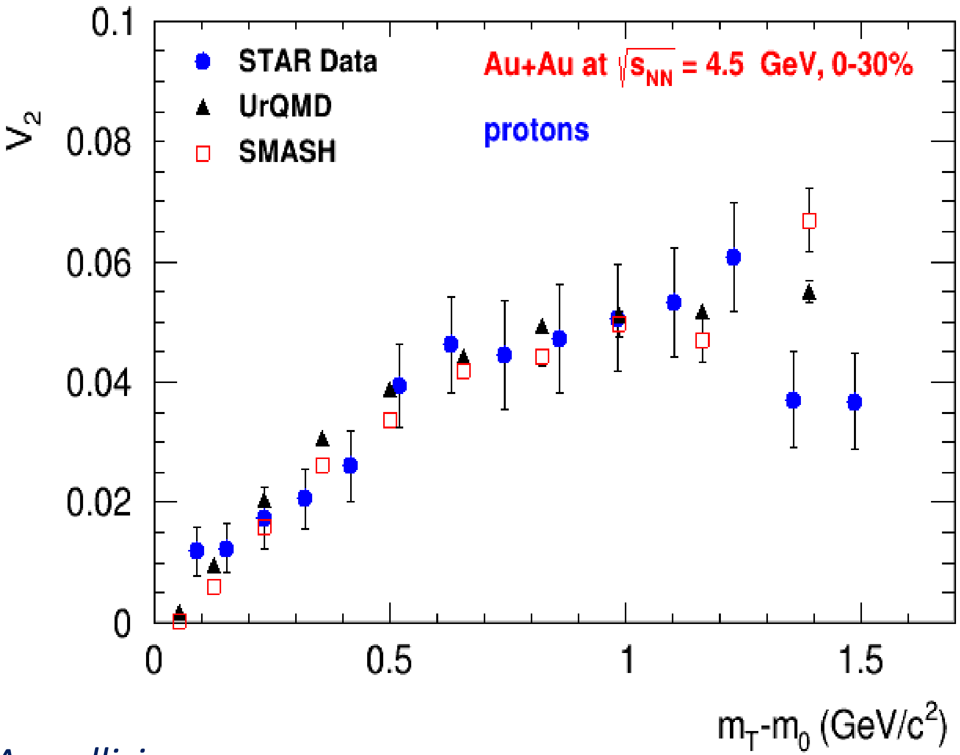




Pure String/Hadronic Cascade models give smaller v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=7.7 GeV

Elliptic flow: Models vs Data comparison

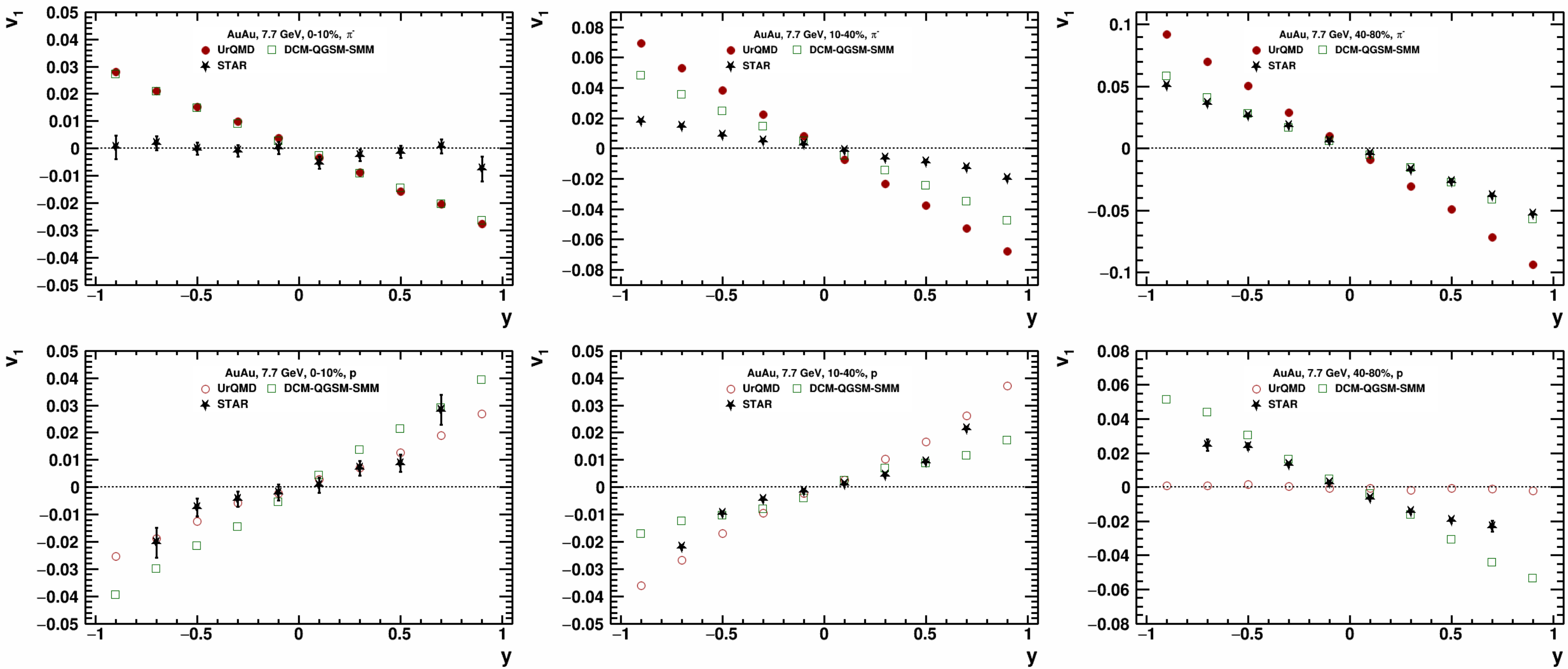




STAR Collaboration: Flow and interferometry results from Au+Au collisions at 4.5 GeV, arxiv.org/abs/2007.14005

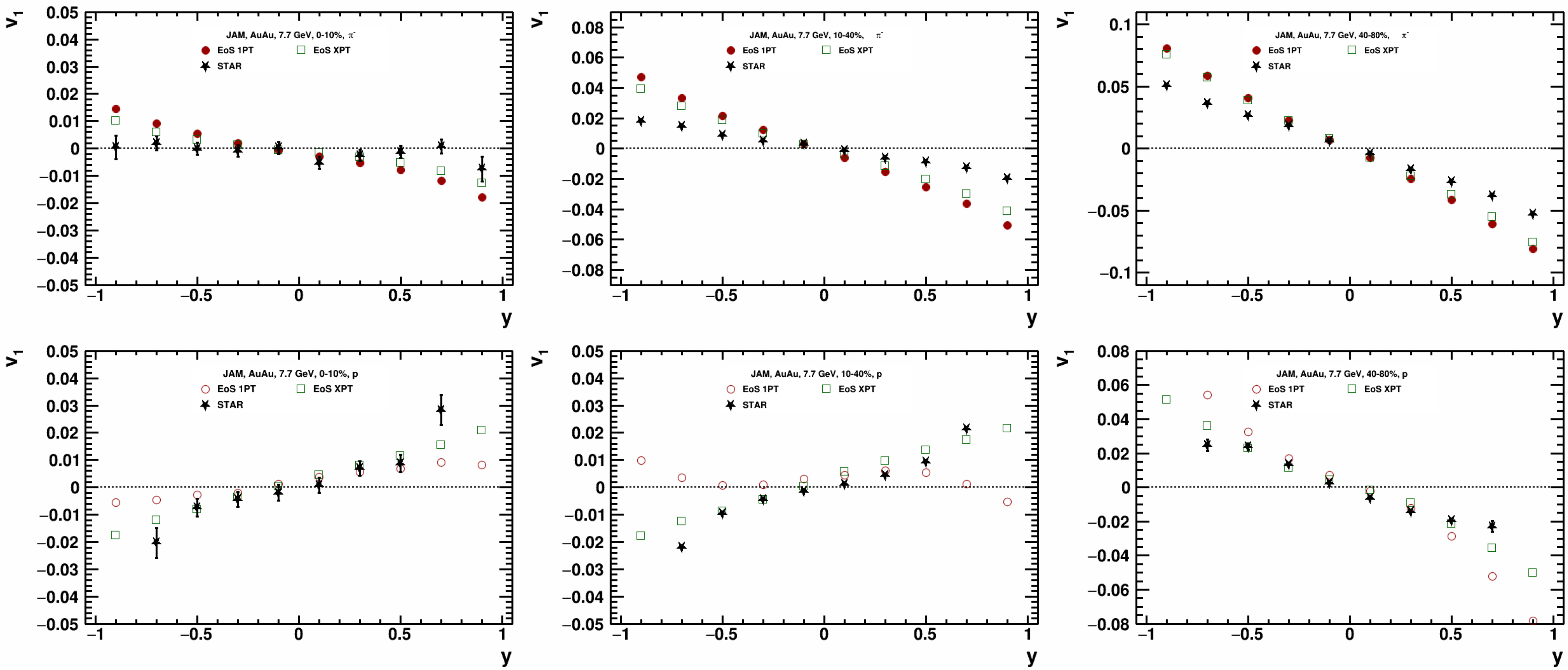
Pure String/Hadronic Cascade models give similar v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$=4.5 GeV

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))

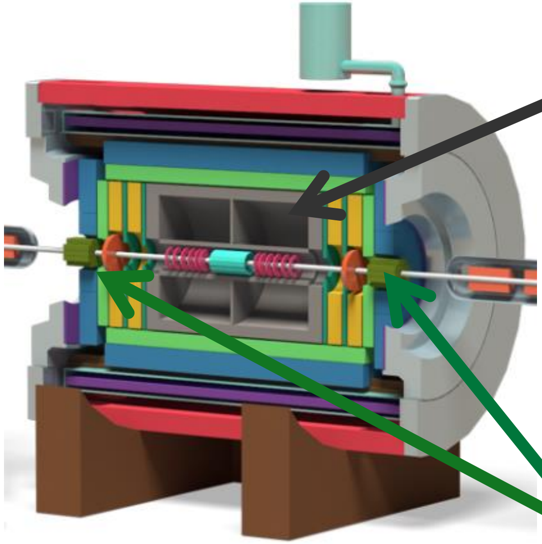
Directed flow: Models vs Data comparison



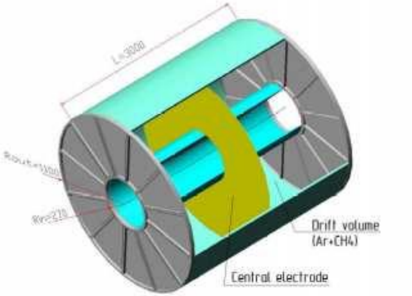
Models JAM (1PT vs XPT EOS) vs STAR published data for Au+Au at $\sqrt{s_{NN}}$= 7.7 GeV (Phys. Rev. Lett. 112, no. 16, 162301 (2014))

Flow performance study at MPD (NICA)

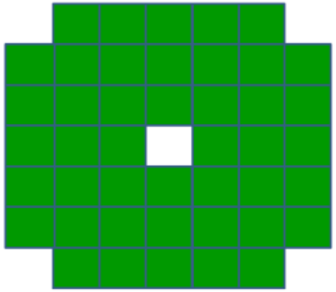
Multi Purpose Detector (MPD)



Time projection chamber (TPC)



Forward Hadron Calorimeter
(FH



EP plane

FHCal (2<|η|<5) or TPC (|η|<1.5)

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

Setup, event and track selection

UrQMD
LAQGSM
→ GEANT4 → Reconstruction → Flow analysis

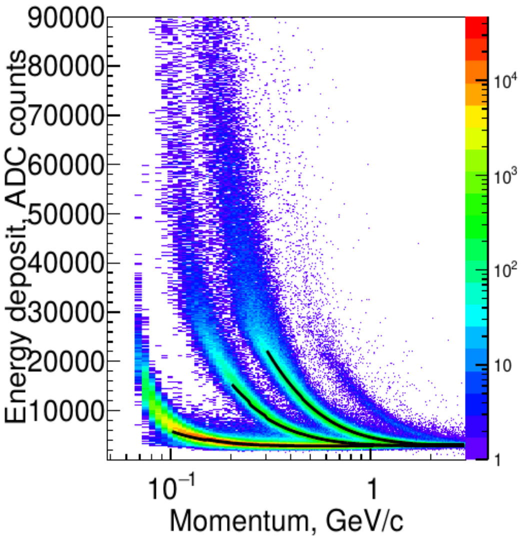
- Au+Au, N_{events}= 8 M events
- *at* $\sqrt{s_{NN}}$ = 4.5, 7.7 and 11 GeV
- Bi+Bi, N_{events}= 8 M events
- *at* $\sqrt{s_{NN}}$ = 7.7 GeV

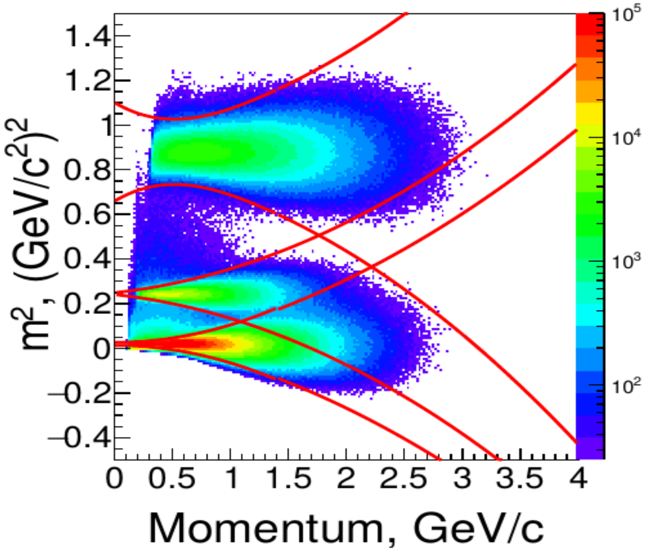
- TPC
- FHCal
- TOF
- ...

- Event classification:
- Track multiplicity
- FHCal energy

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

MPDRoot, December 2019





Event plane method implementation in MPD (NICA)

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

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

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

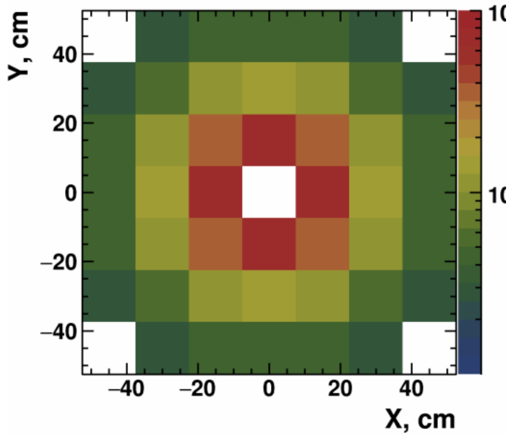
$$TPC\ EP{:}\ m = 2,\ \omega = p_{\mathrm{T}}$$

- 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)

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

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

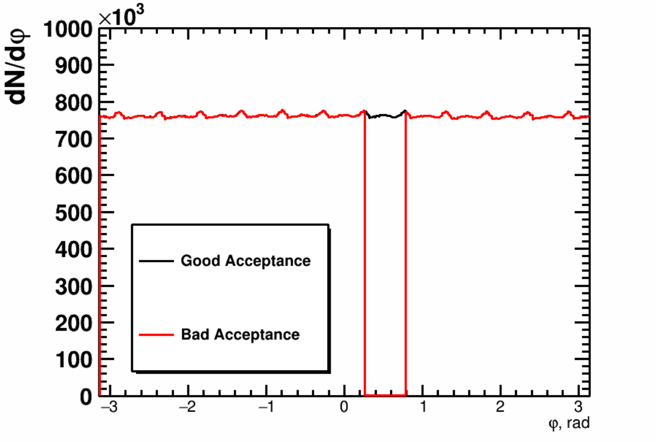
$$v_n = \frac{\langle \cos[n(\Psi_{RP} - \Psi_m^{EP})] \rangle}{Res_n\{\Psi_m^{EP,true}\}}$$

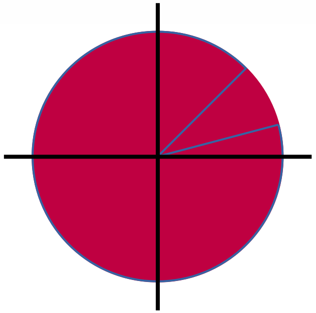


Energy distribution in FHCal

Acceptance filter

TPC

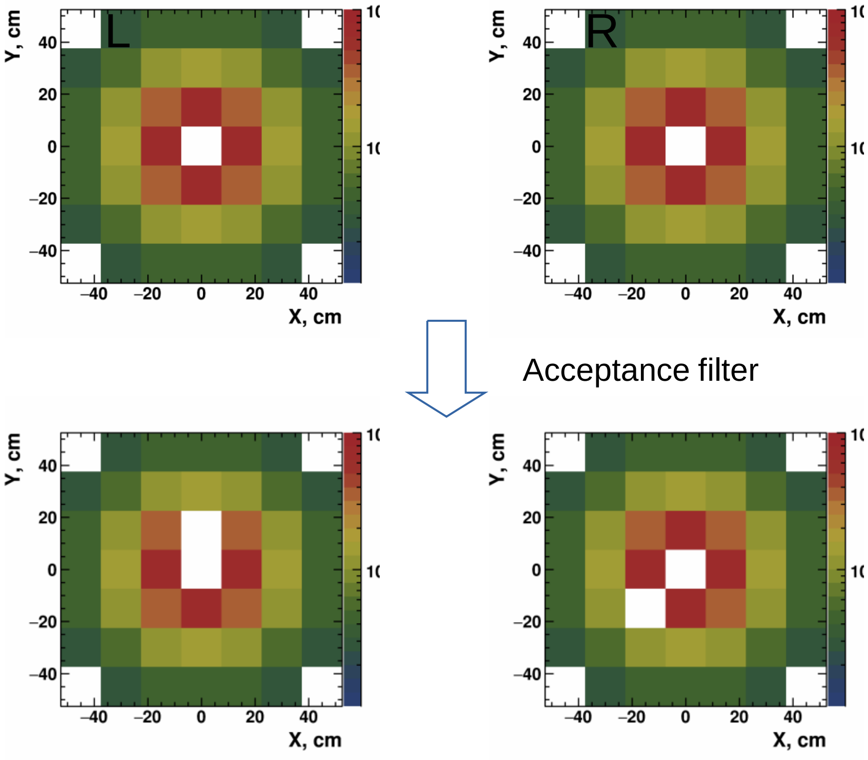




Area 15°< φ < 45° is off

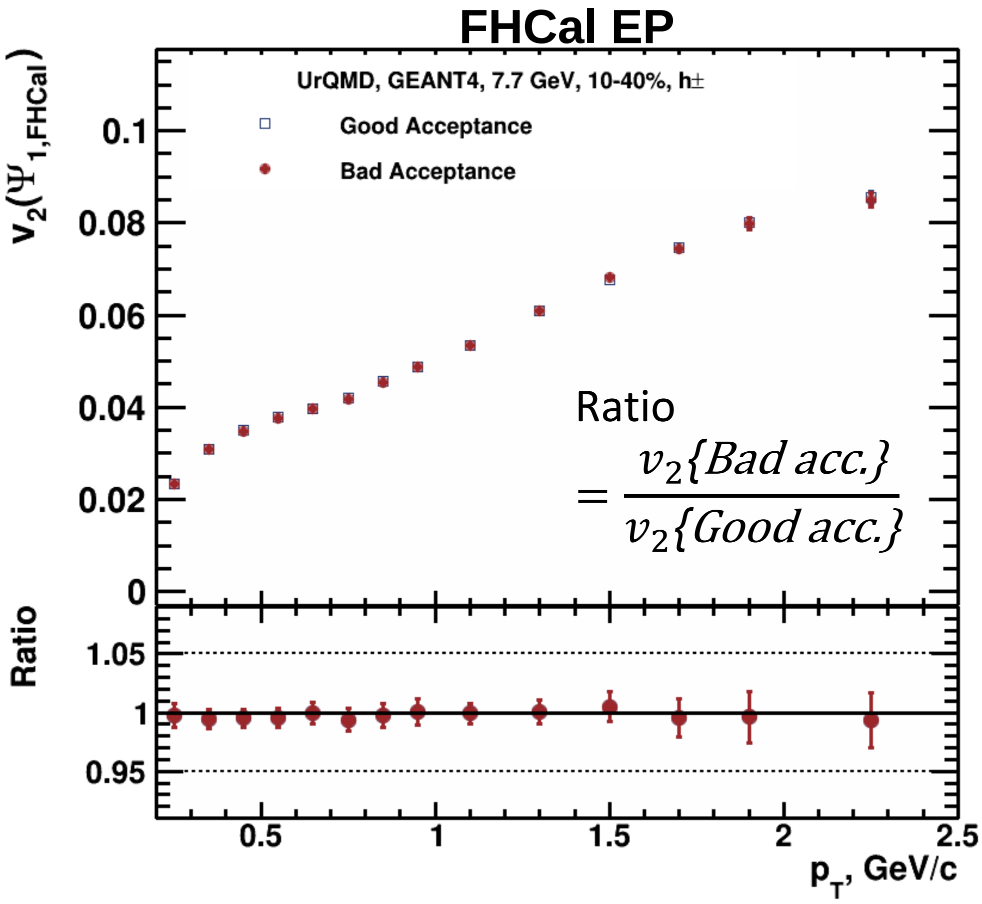
FHCal

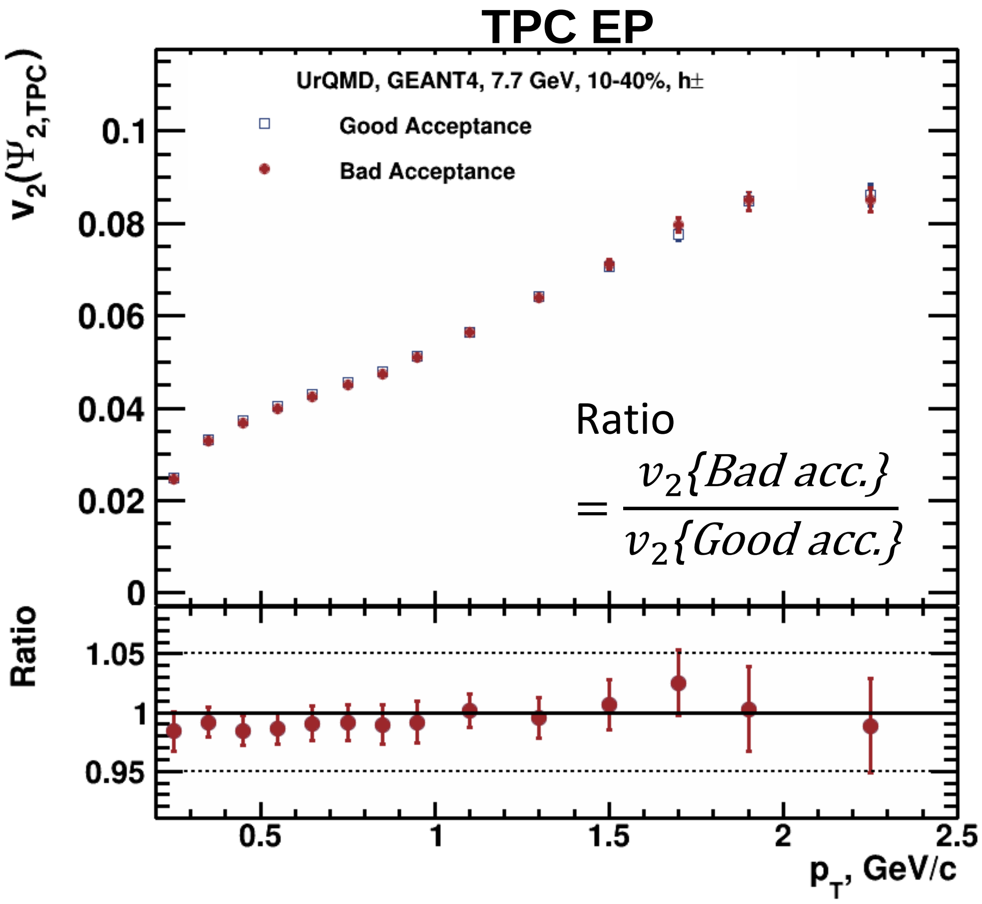
FHCal



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

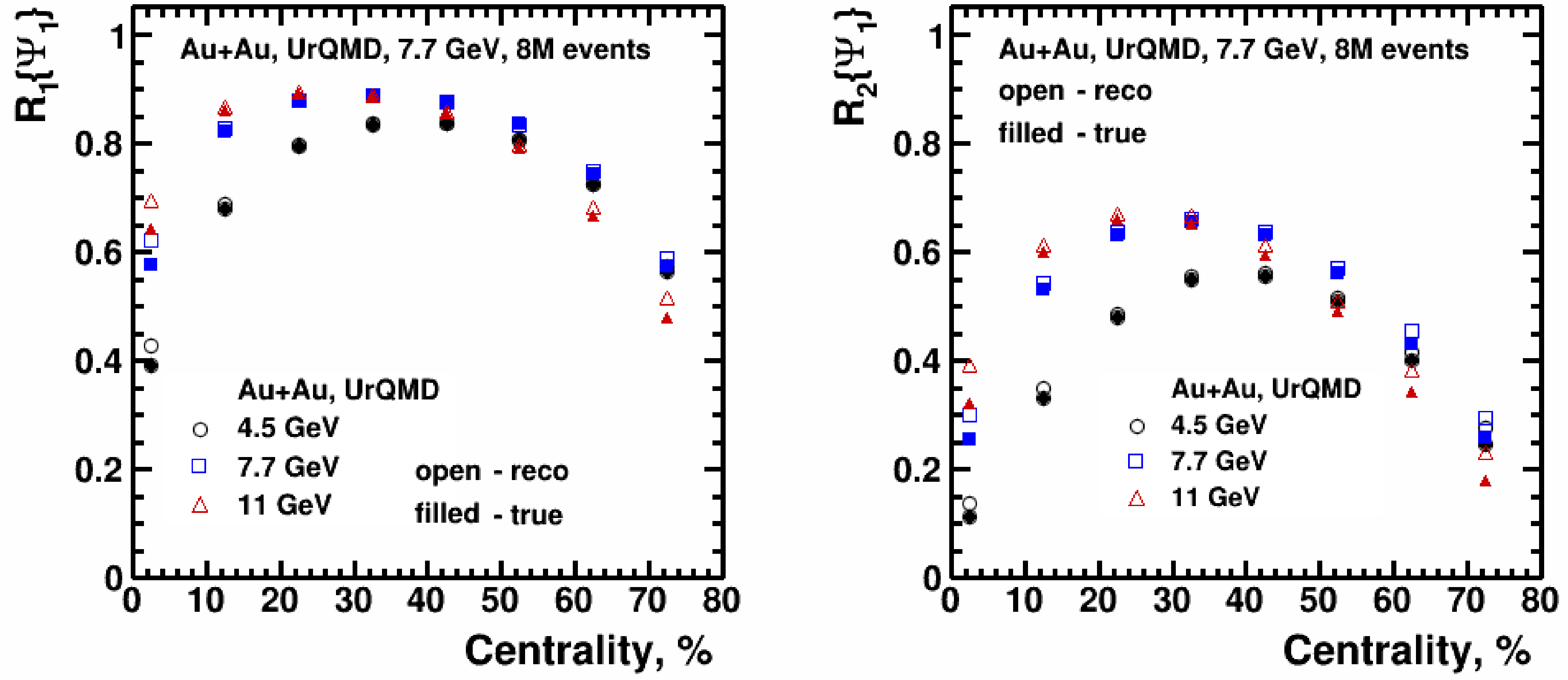
$v_2(p_T)$: check of corrections





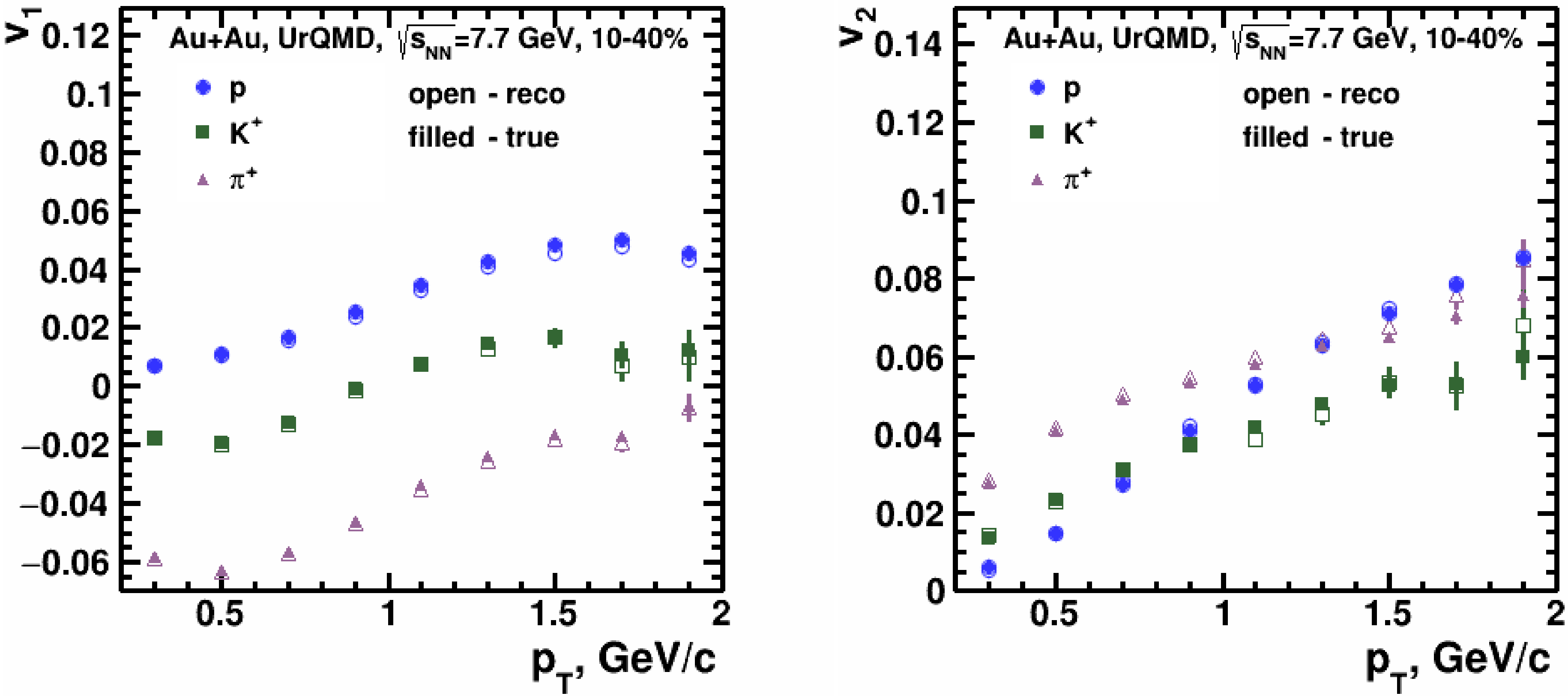
Good agreement with results for ideal (Good) acceptance

EP Resolution: energy dependence



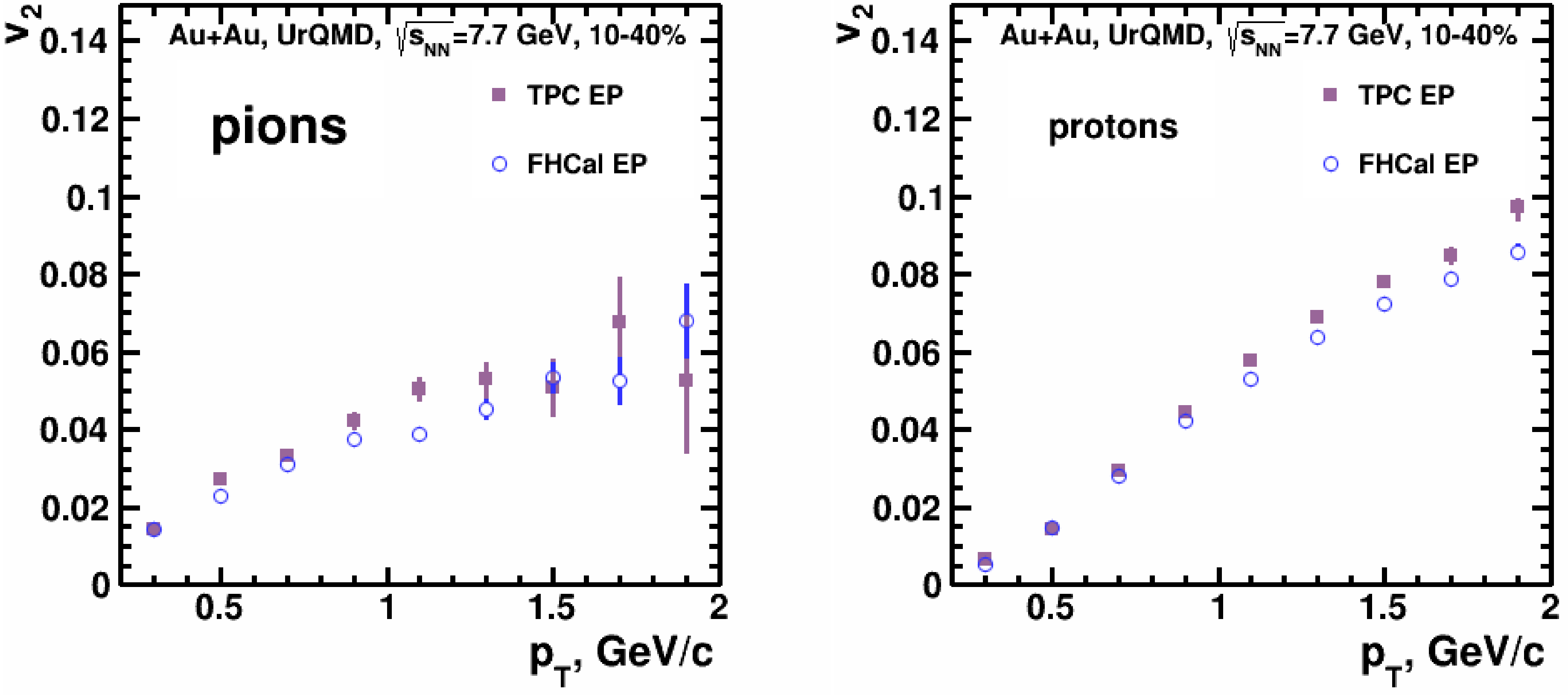
Good performance in the centrality range 0-80% for NICA collision energy range

p_T-dependence of v_1 and v_2 of reconstructed signal



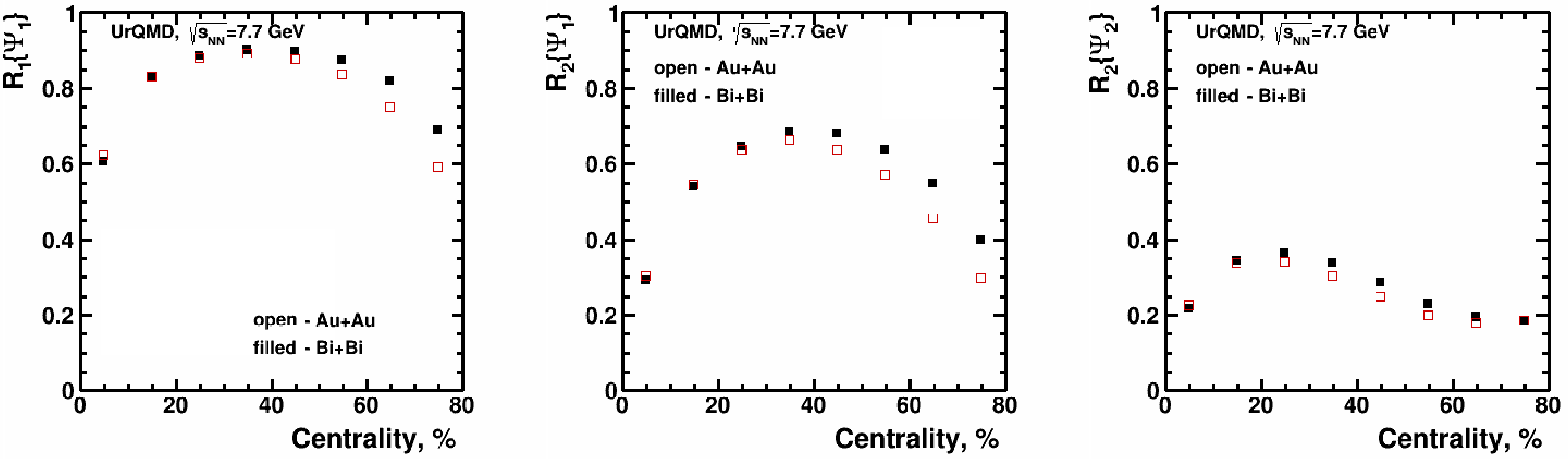
Both directed and elliptic flow results after reconstruction and resolution correction are consistent to that of MC simulation

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



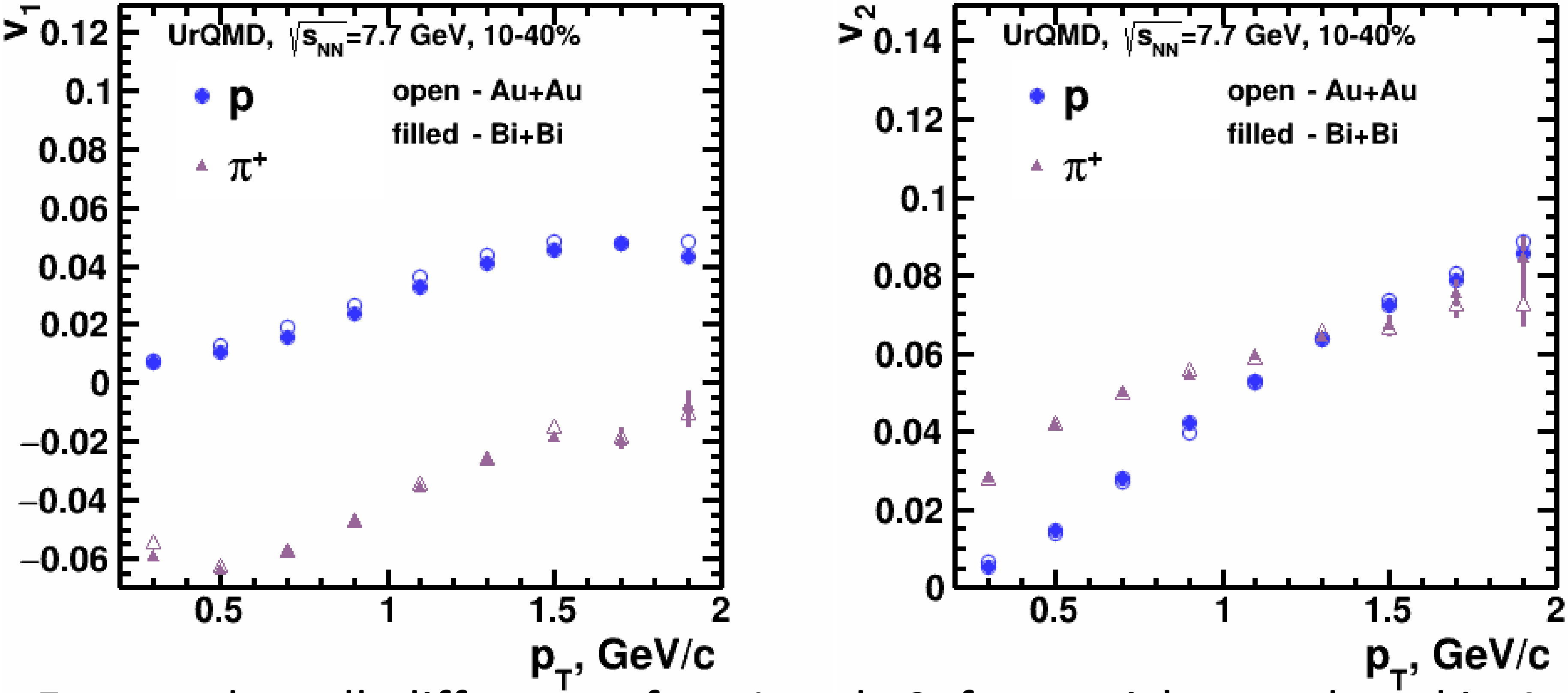
Expected small difference between v_2 measured with respect TPC ($\Psi_{2,EP}$) and FHCal ($\Psi_{1,EP}$)

EP Resolution: Bi+Bi vs Au+Au



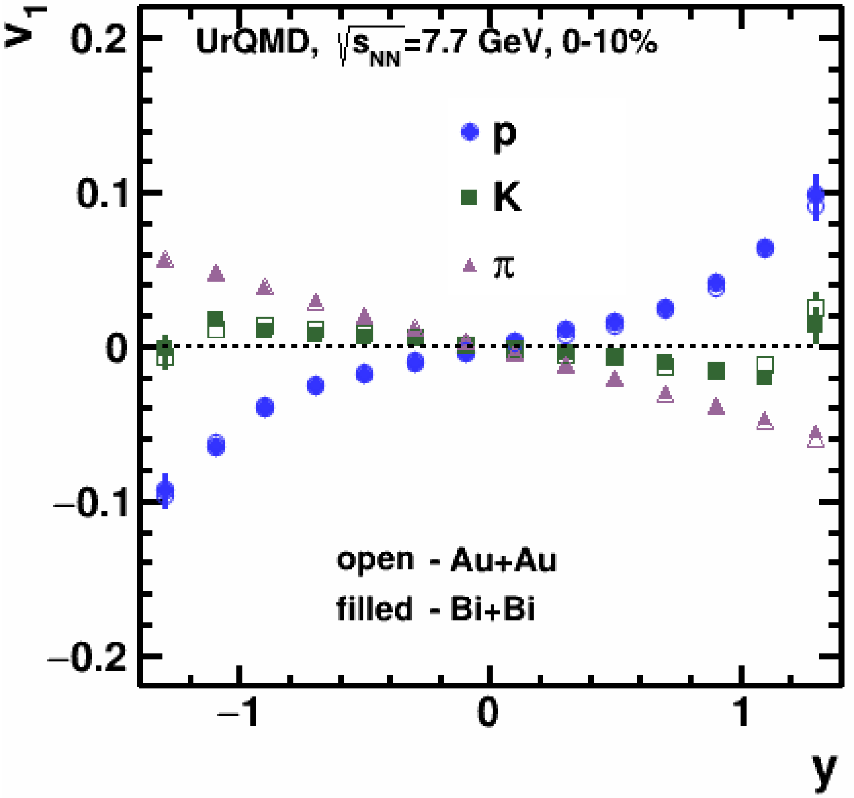
Expected small difference between EP resolutions for Au+Au and Bi+Bi

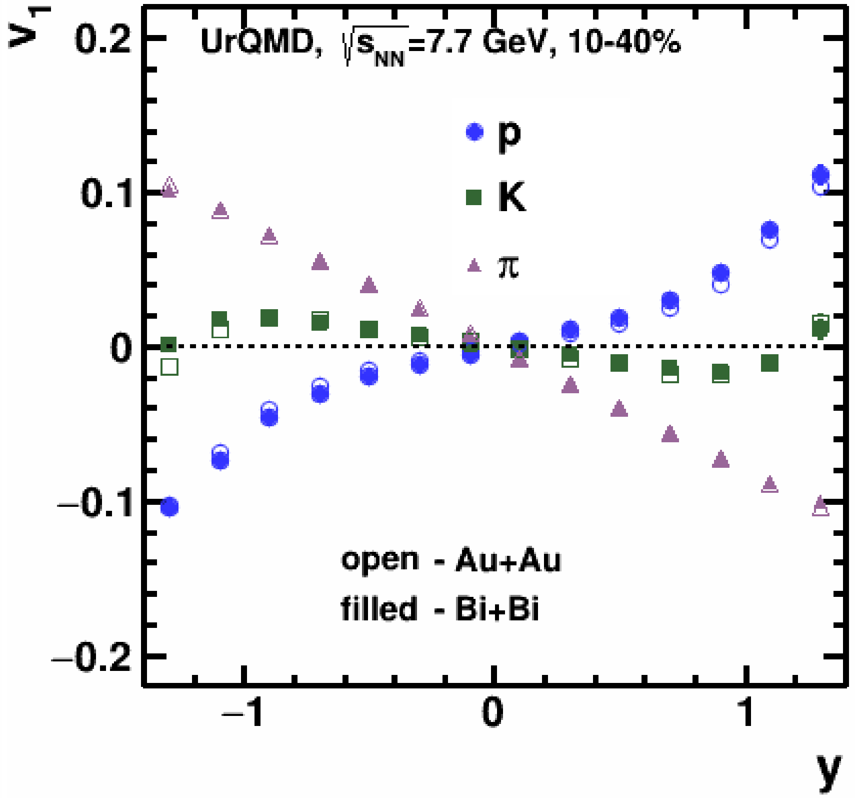
$v_n(p_T)$: Bi+Bi vs Au+Au



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.

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)
  - Event plane from FHCal and TPC
- Reconstructed v_1,v_2 are in agreement with MC generated data for Au+Au and Bi+Bi

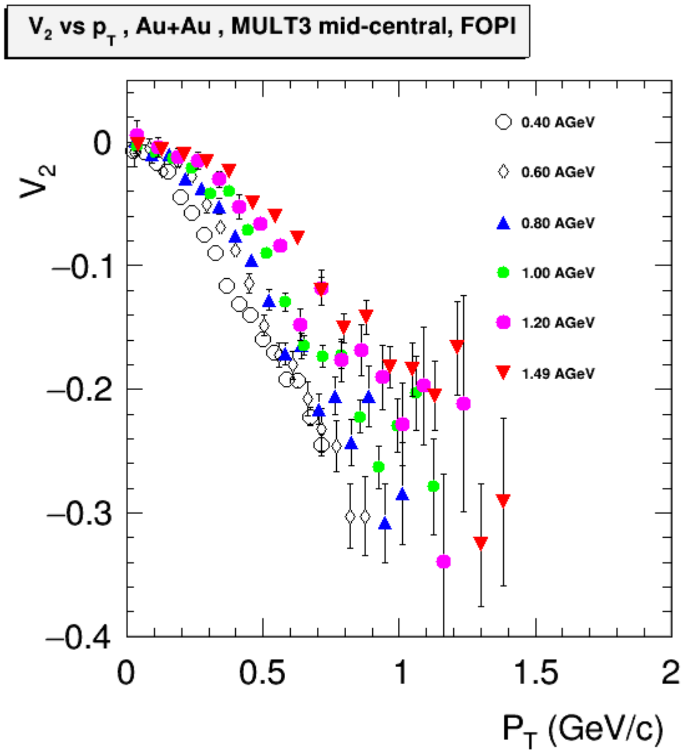
- **Model/Data comparison:**
- $v_2(p_T)$ from 3D hydro model vHLLE + UrQMD and AMPT model are in a good agreement with STAR data at $\sqrt{s}$NN=7.7 GeV
- Pure string/hadronic cascade models give smaller v_2 signal compared
- to STAR data for Au+Au at $\sqrt{s_{NN}}$=7.7 GeV, but in good agreement with 4.5 GeV data.
- Elliptic flow are sensitive to the EoS (1PT or XPT) and η/s
- The situation with good model description worse for directed flow

Thank you for your attention!

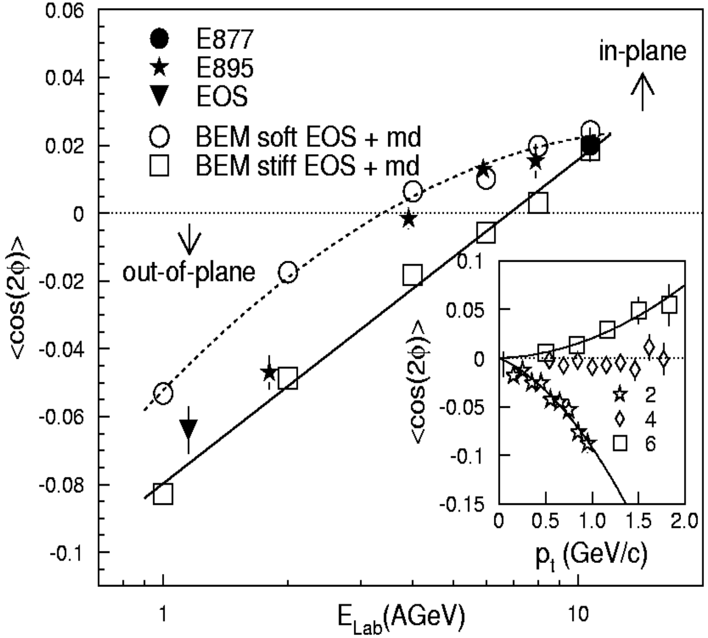
Backup

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

Anisotropic Flow at BES 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

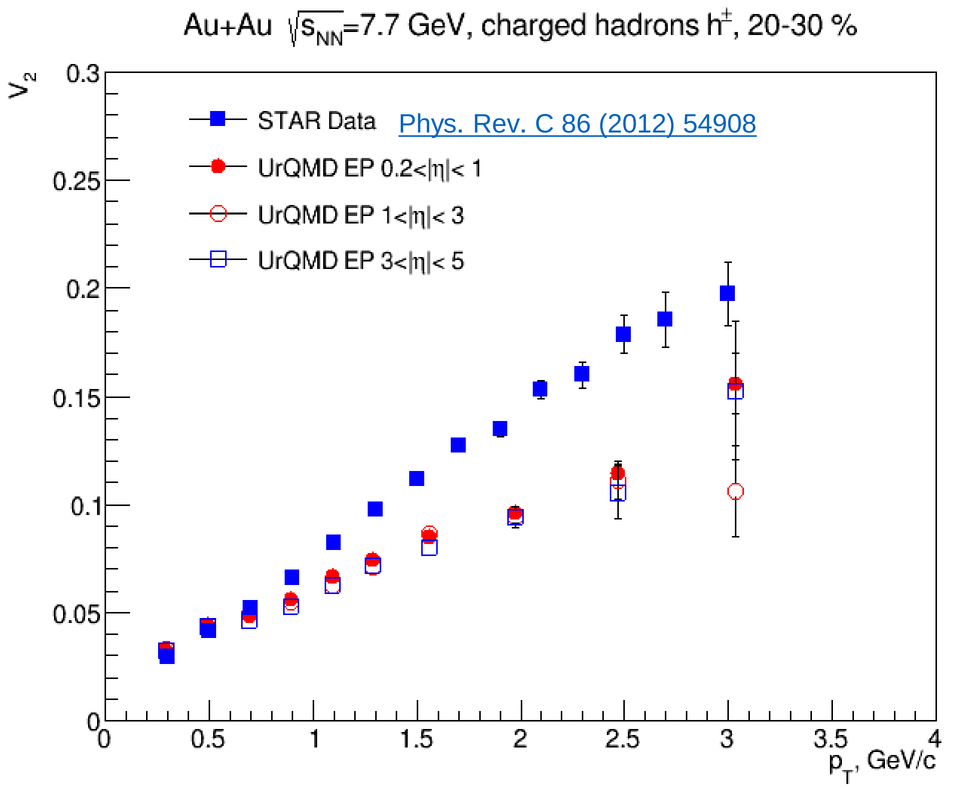
(3) STAR Collaboration Au+Au at 4.5, 7.7 , 11.5, 14.5, 19.6, 27 GeV, 39, 62.4, 200 GeV

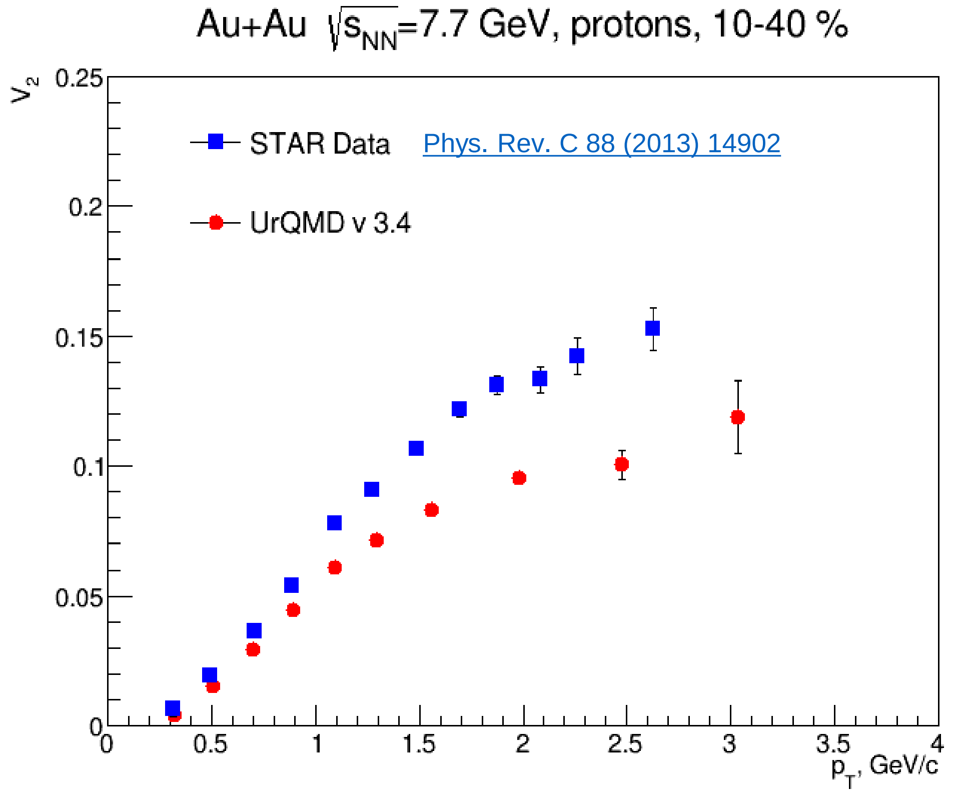
Anisotropic flow at NICA energies   Models:

(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)

BES: differential elliptic flow: UrQMD

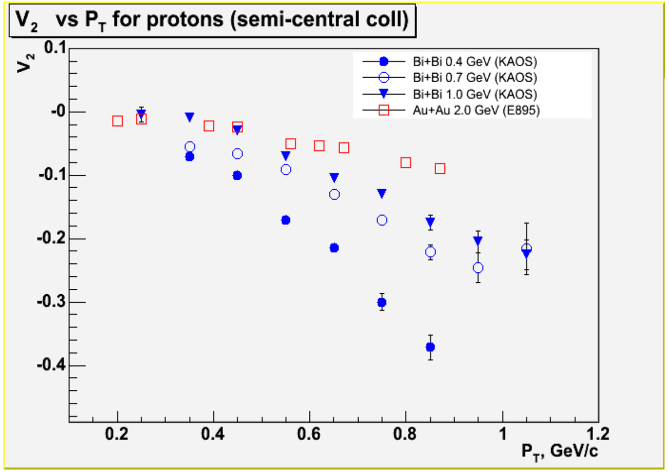


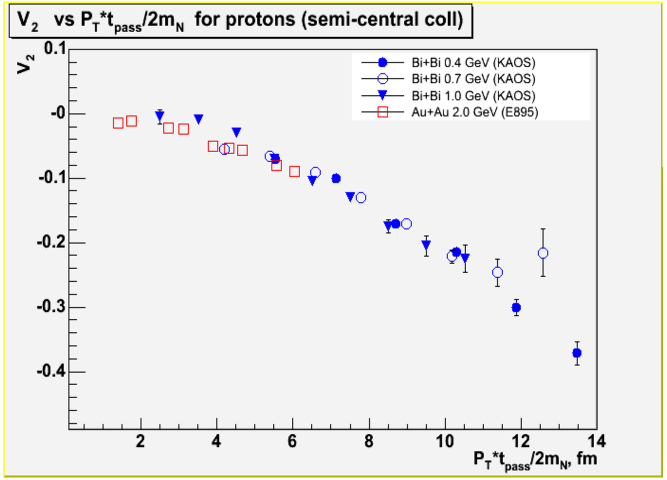


What about other “hadronic” models: SMASH, JAM, HSD? - Under investigation

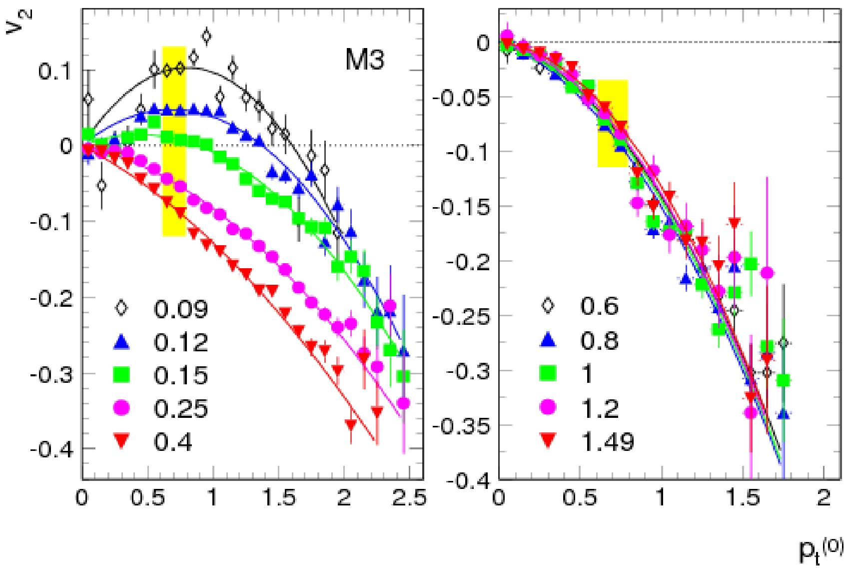
v_2 Flow at SIS-AGS: scaling relations

(KAOS – Z. Phys. A355 (1996);
(E895) - PRL 83 (1999) 1295





FOPI: v_2 of protons from
Elab=0.09 to 1.49 GeV
Phys.Lett. B612 (2005) 173-180

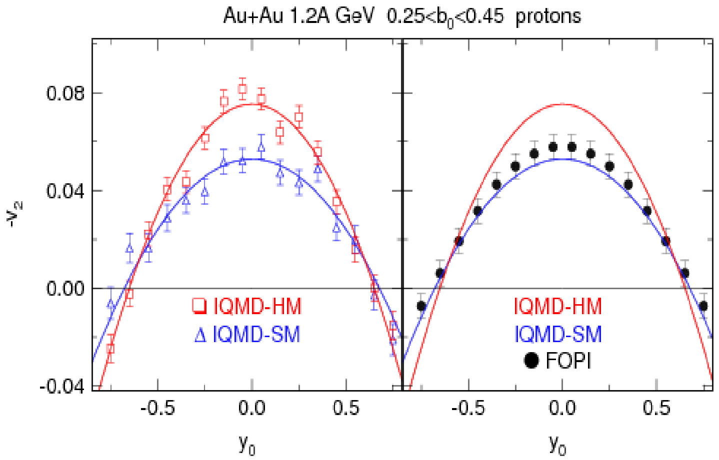


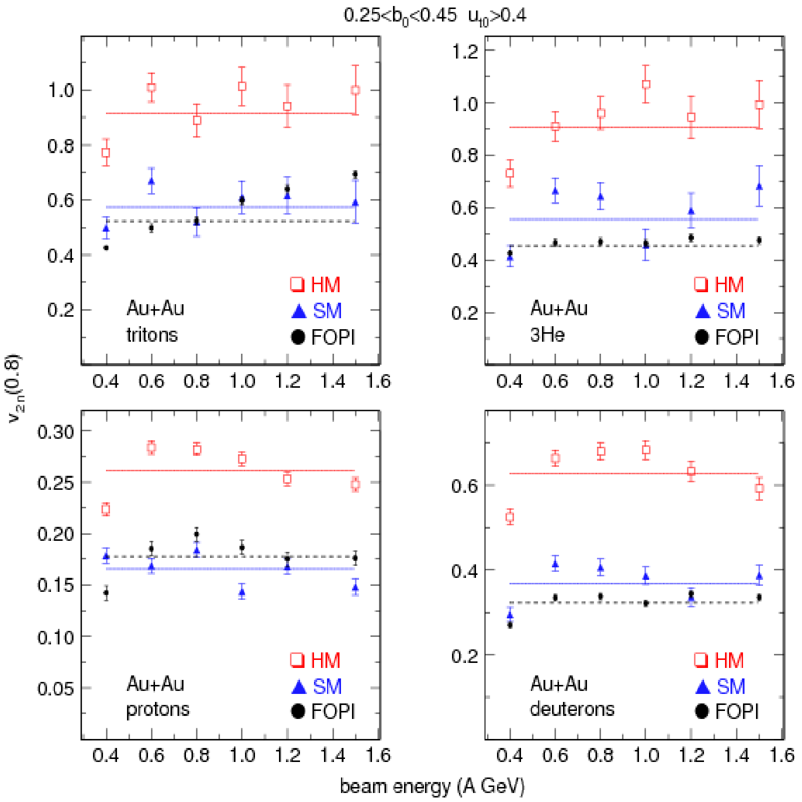
The rather good scaling observed suggest that c_s does not change significantly over beam energy range 0.4 – 2.0 AGeV.

Flow at SIS: rapidity dependence of v2 and EOS

HM – stiff momentum dependent with K=376 MeV
SM – soft momentum dependent with K=200 MeV

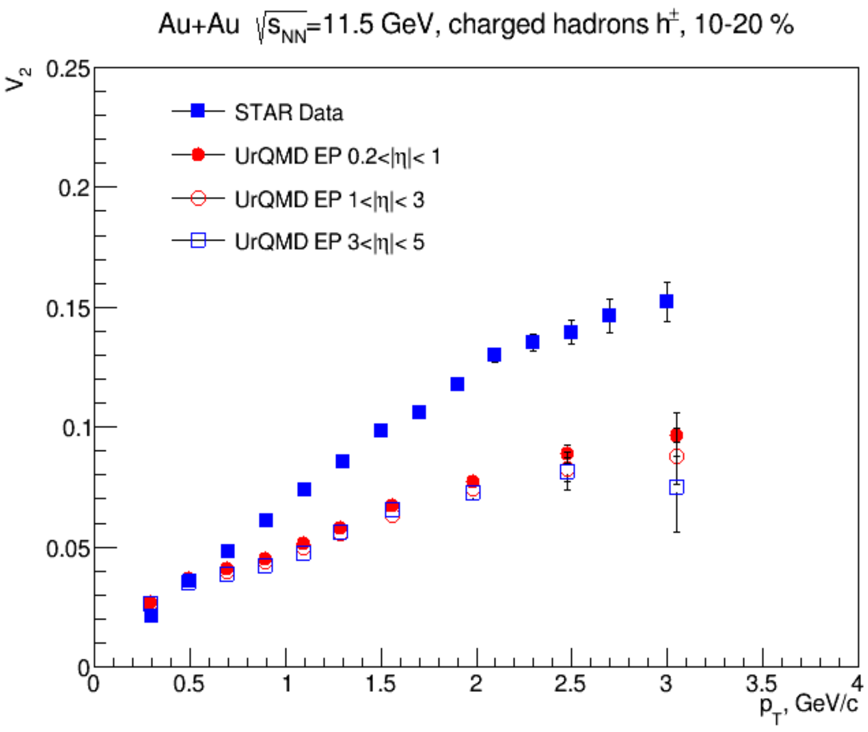
FOPI data : Nucl. Phys. A 876 (2012) 1
IQMD : Nucl Phys. A 945 (2016)

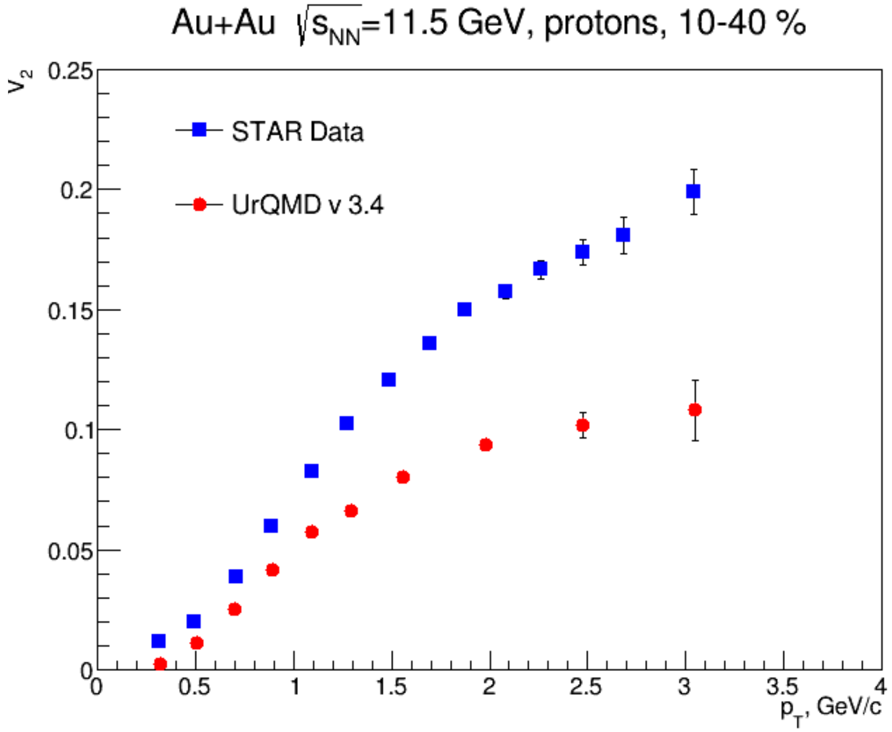




V2n=|V20|+|V22|
Fit: V2(y0)=V20+V22*Y0^2

BES: differential elliptic flow: UrQMD

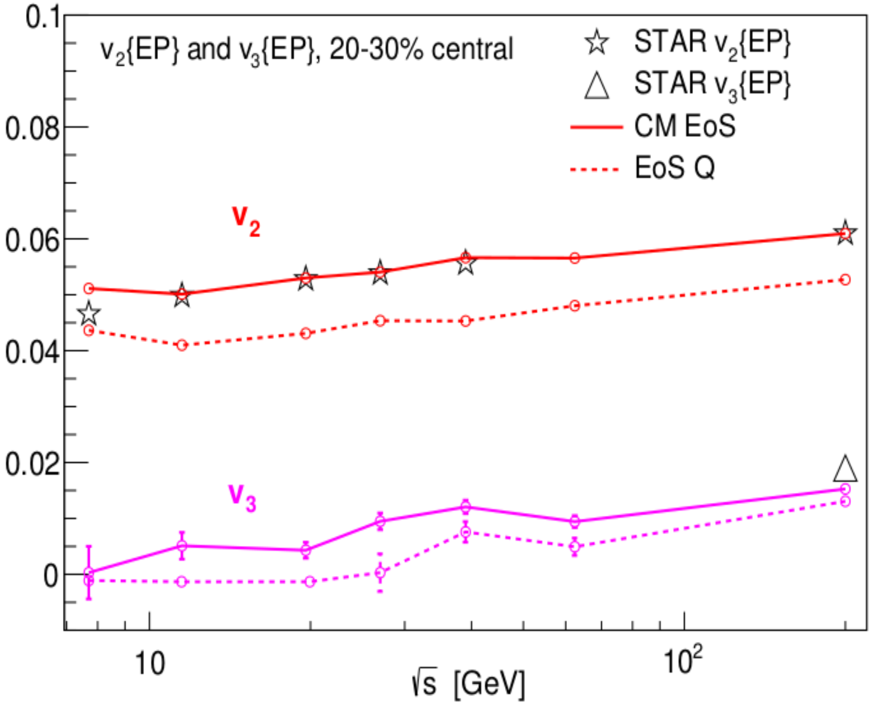


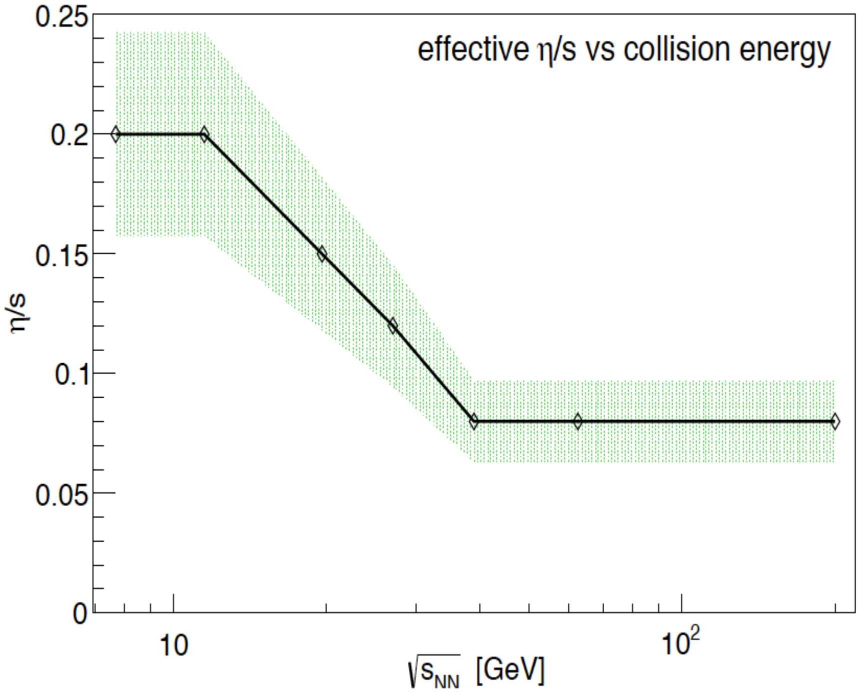


What about other "hadronic" models: SMASH, JAM, HSD? - Under investigation

Elliptic and triangular flow of charged hadrons at RHIC BES

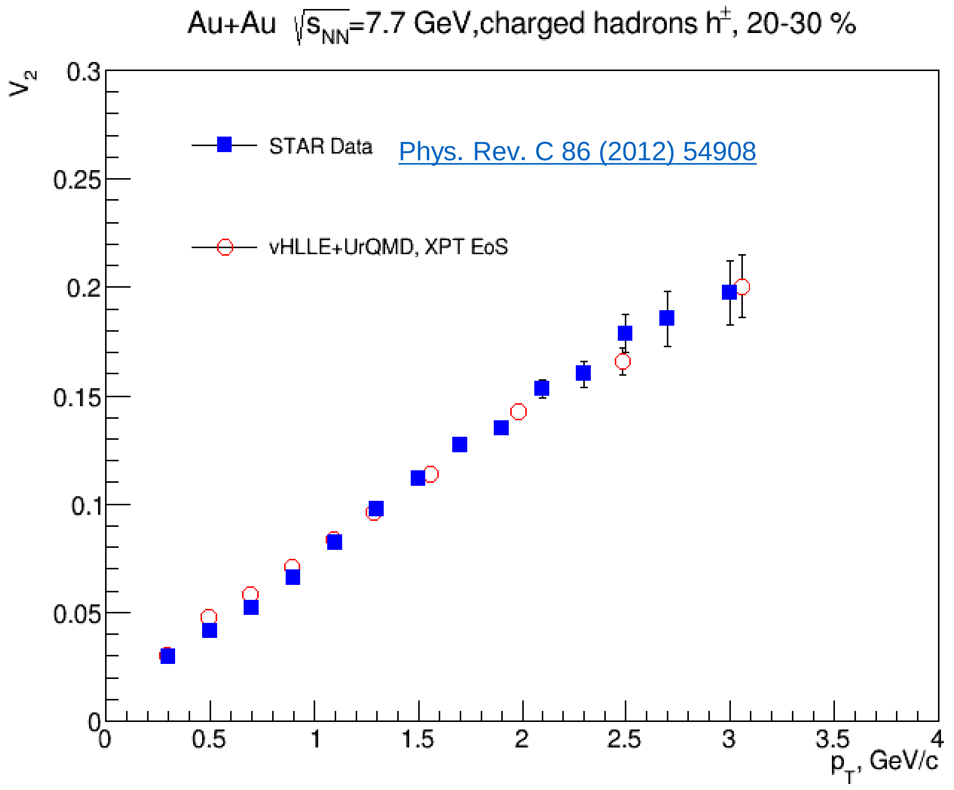
Iu.A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher, Phys.Rev. C91 (2015) no.6, 064901

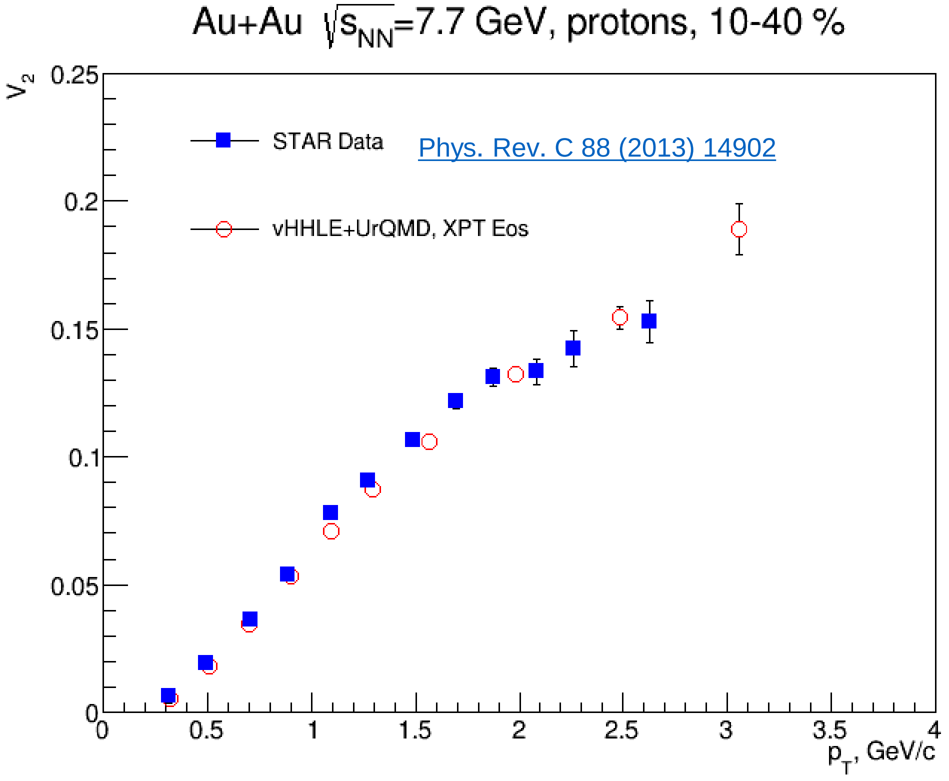




Hybrid model: UrQMD + 3D hydro model vHLLE + UrQMD
Shows good agreement with published STAR data for integrated $v_n(\sqrt{s_{NN}})$ from BES-I

Differential elliptic flow: 3D hydro vHLLE + UrQMD



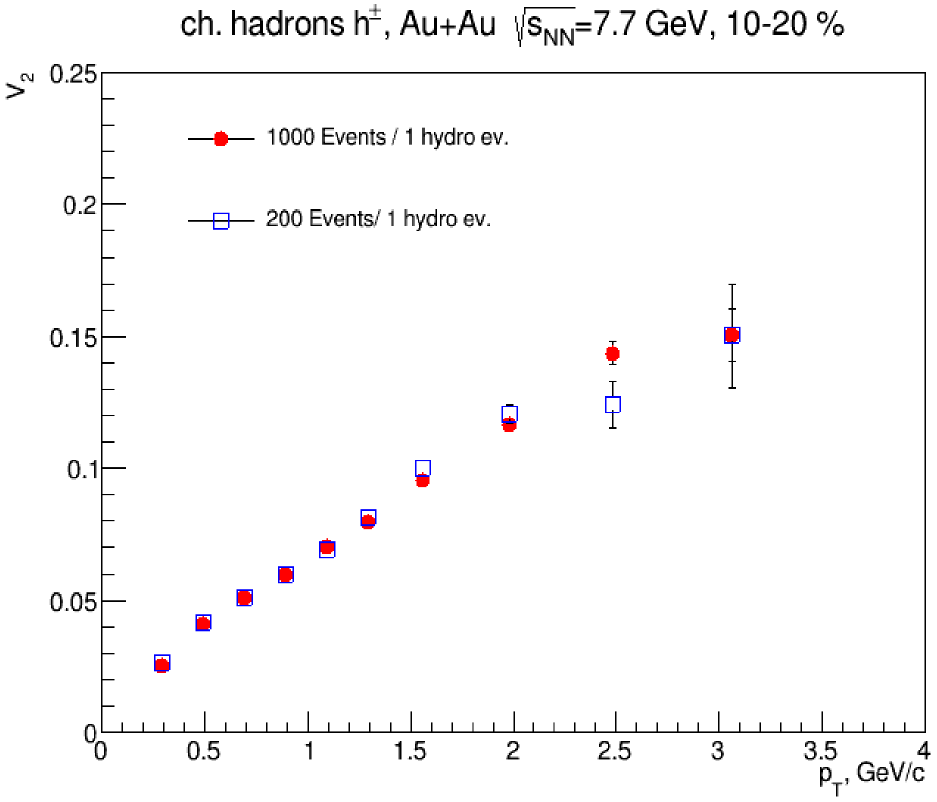


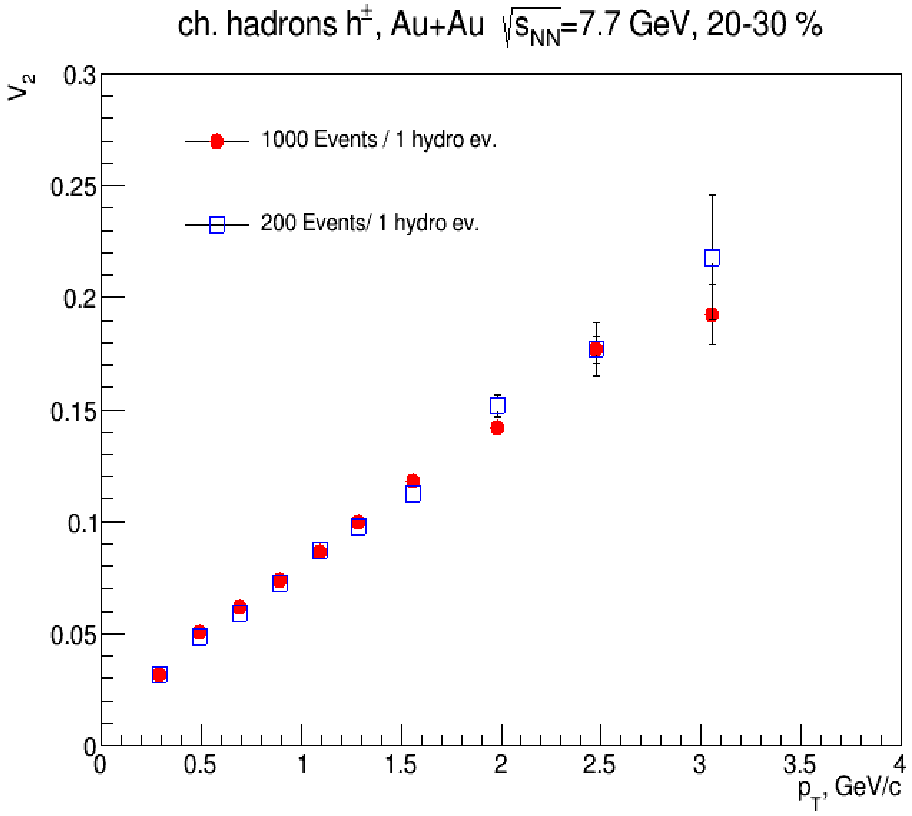
3D hydro model vHLLE + UrQMD (XPT EoS), η/s = 0.2 + param. from Phys.Rev. C91 (2015) no.6, 064901

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

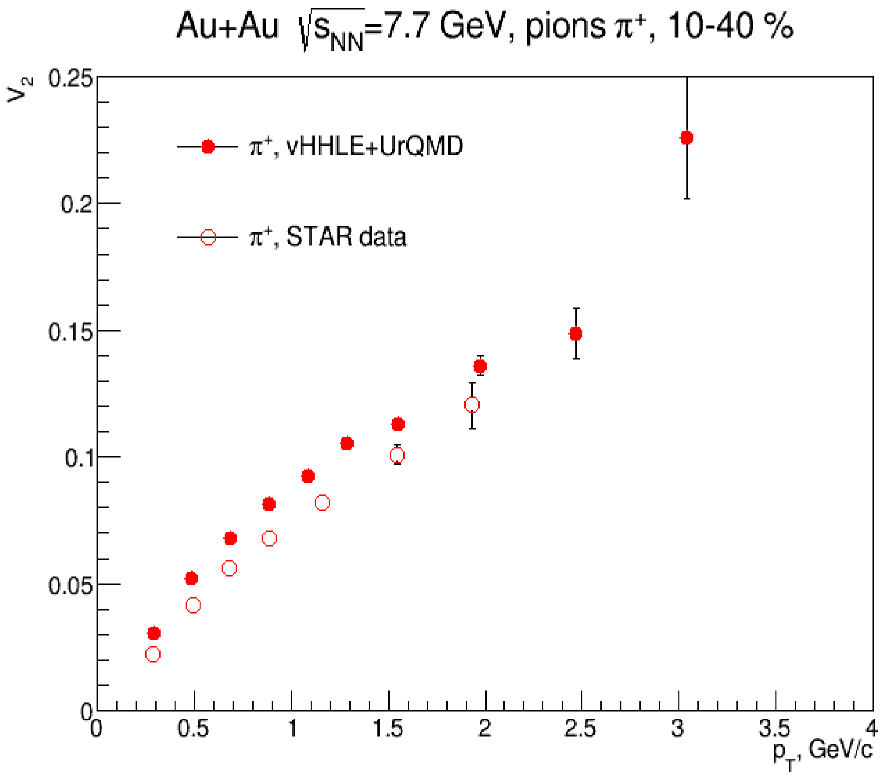
Good agreement with STAR published data

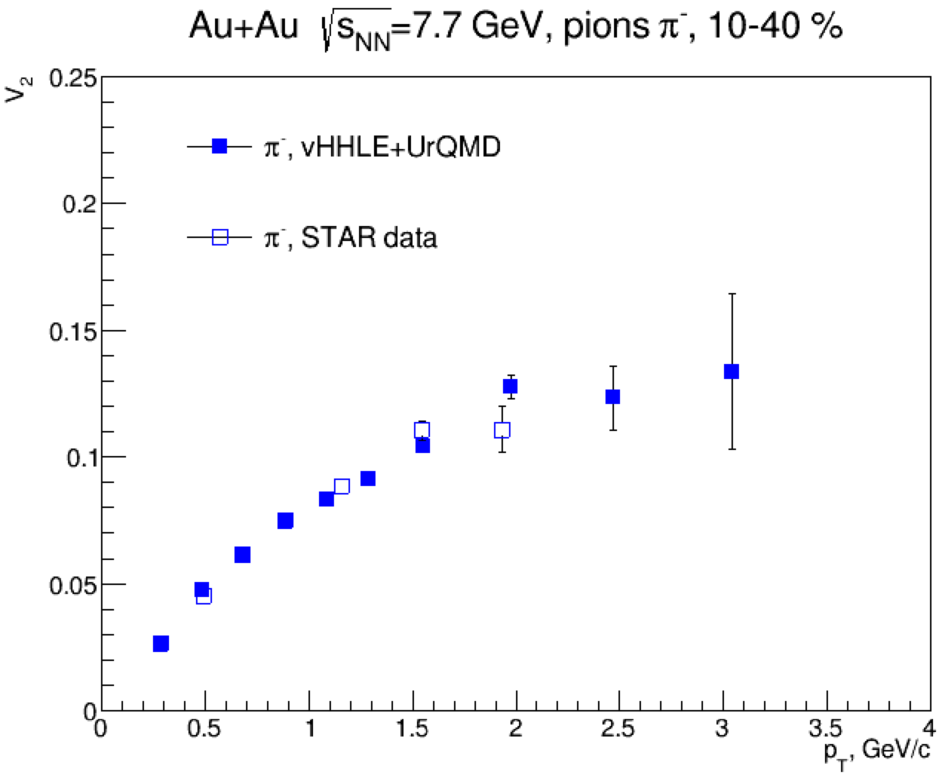
Differential elliptic flow: 3D hydro vHLLE + UrQMD





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!