MPD performance in the fixed-target mode

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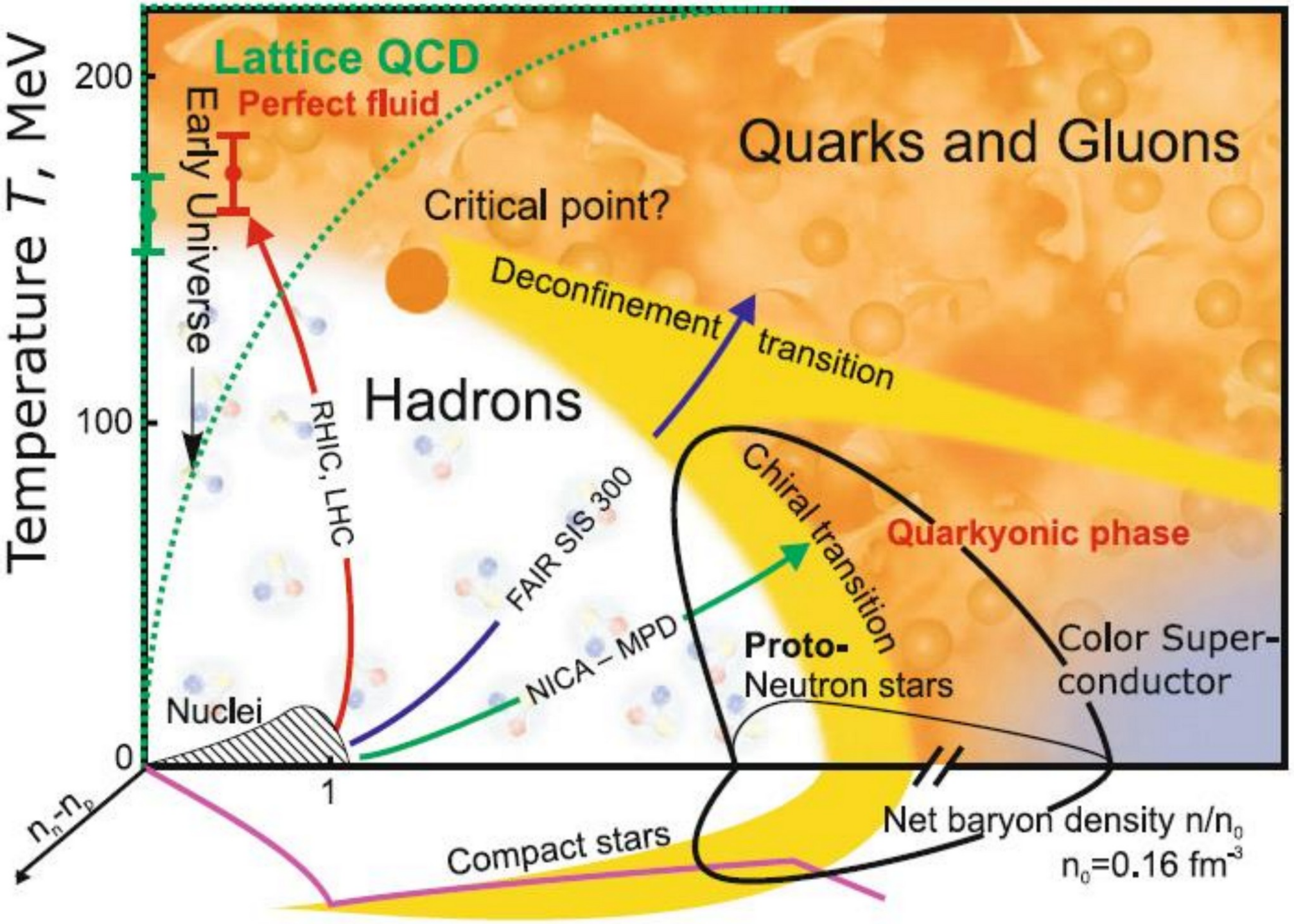
Relativistic heavy-ion collisions



Relativistic heavy-ion collisions allows us to study QCD phase diagram

- **High beam energies ($\sqrt{s_{NN}} > 100\ GeV$):**
  - High T, $\mu_B \approx 0$
  - Evolution of the early Universe
- **Low beam energies ($2 < \sqrt{s_{NN}} < 11\ GeV$):**
  - Intermediate T, high μ_B
  - Inner study of the compact stars

MPD and BM@N will study QCD matter at extreme μ_B

Several future (MPD) and ongoing (NA61/SHINE, STAR) experiments cover the same beam energy range

EOS for high baryon density matter

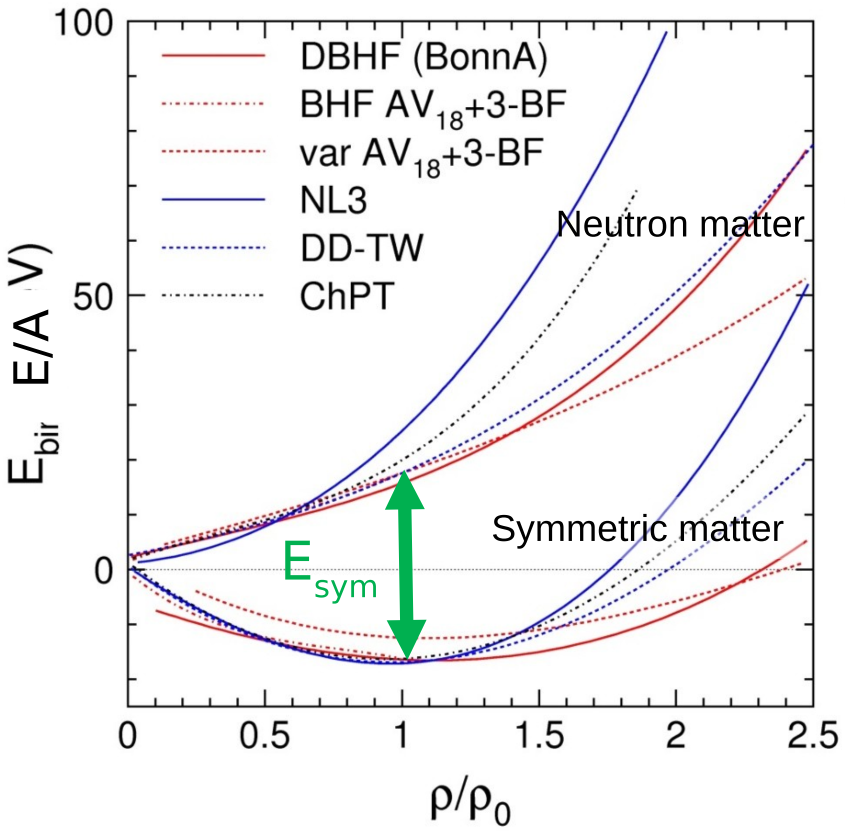
The binding energy per nucleon: $E_A(\rho,\delta) = \boxed{E_A(\rho,0)} + \boxed{E_{sym}(\rho)}\delta^2 + O(\delta^4)$

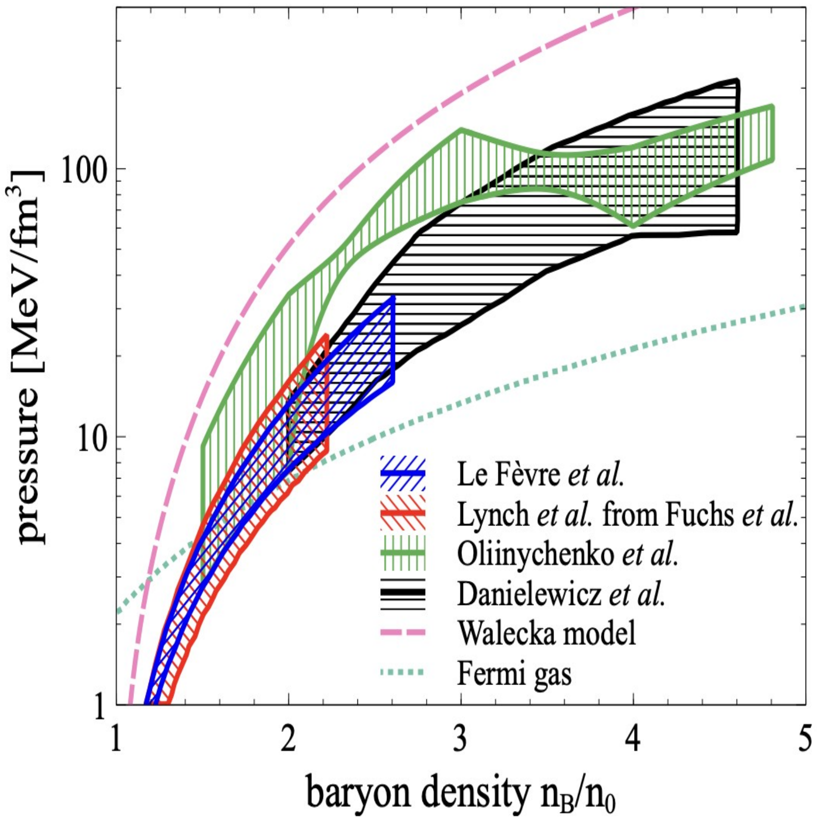
Isospin asymmetry:

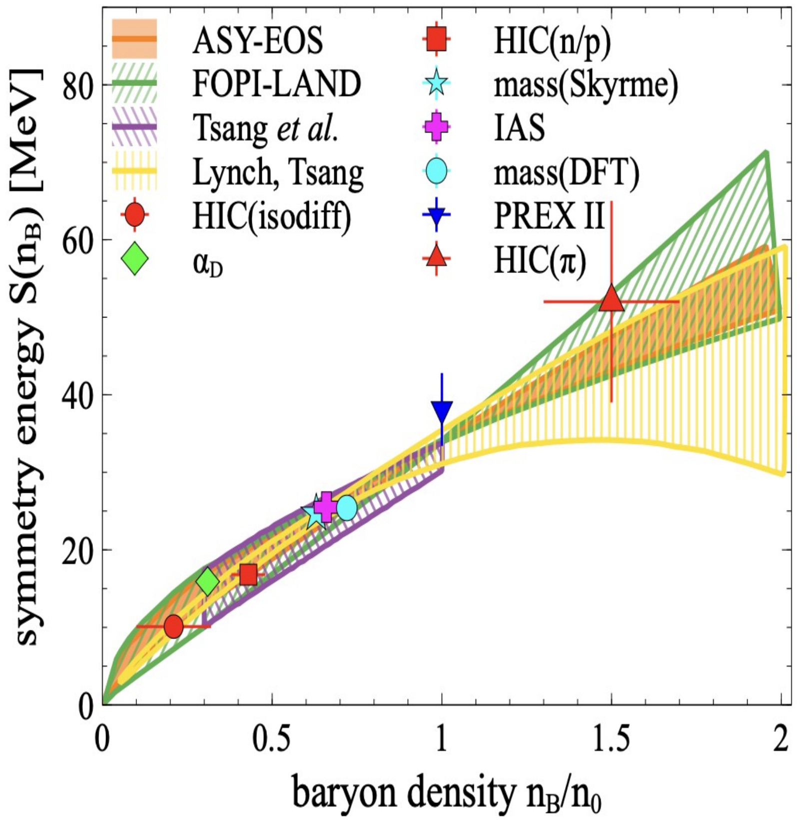
$\delta = (\rho_n - \rho_p)/\rho$

Symmetric matter

Symmetry energy







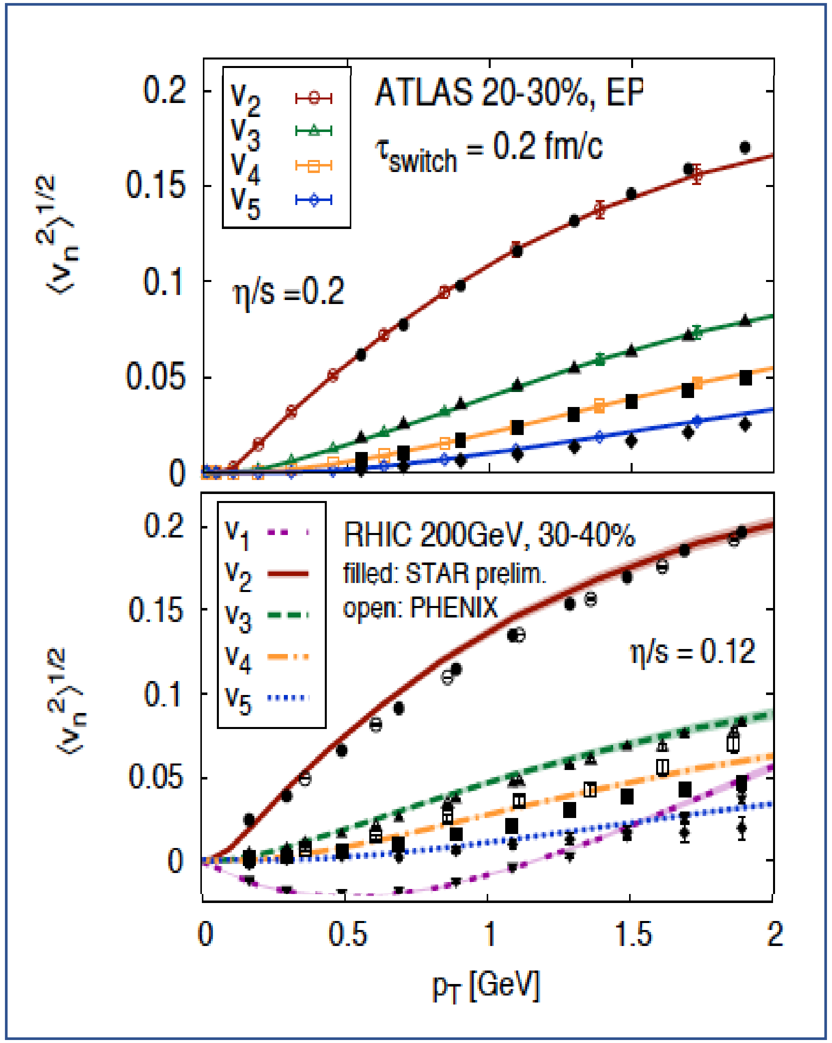
Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5

A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080

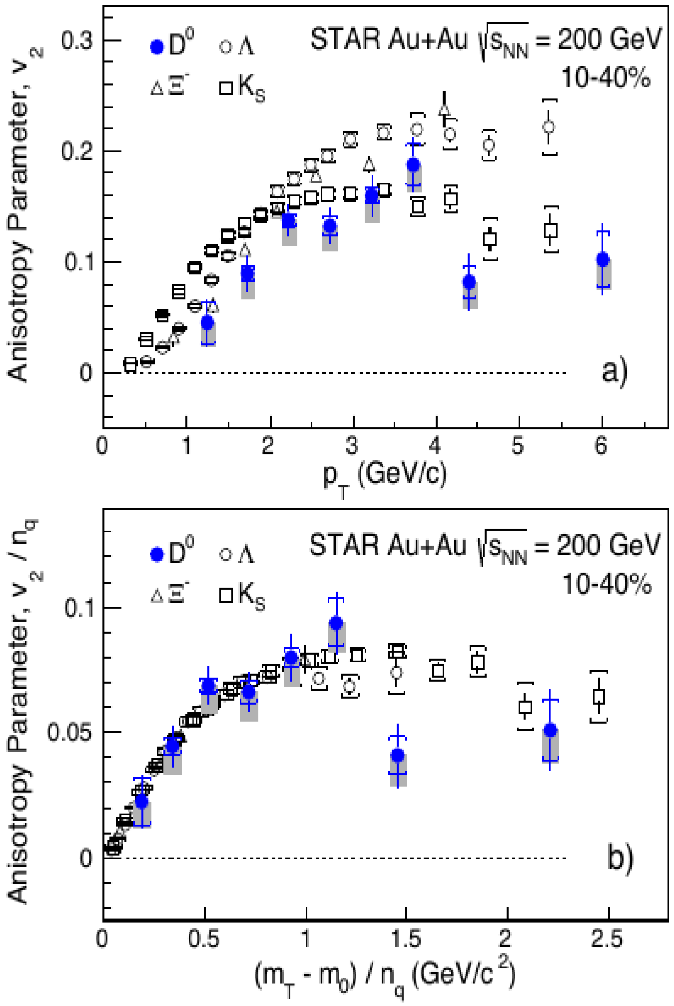
New data is needed to further constrain transport models with hadronic d.o.f.

Anisotropic flow at LHC/RHIC

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



STAR PRL118 (2017) 212301



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

$$v_n = \langle \cos[n(\phi - \Psi_{RP})] \rangle$$

v_1 – directed flow, v_2 – elliptic flow

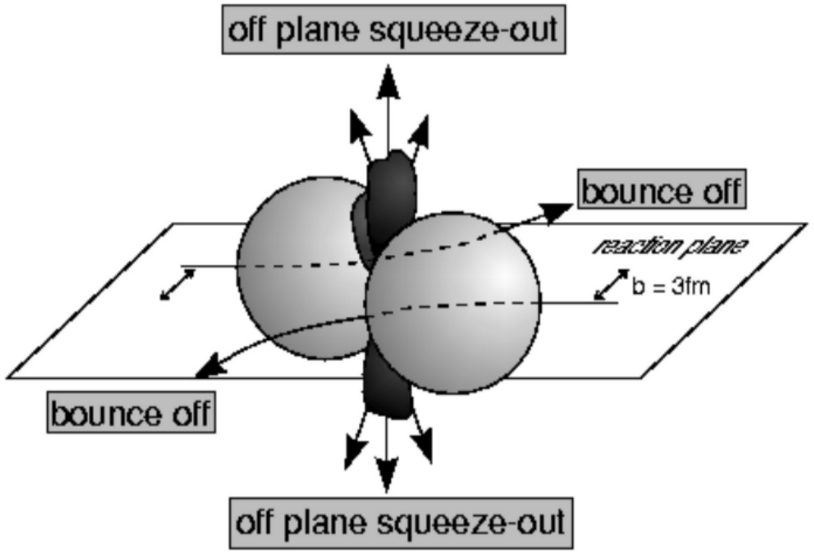
$v_n(p_T, \textbf{Centrality})$ - sensitive to the early stages of the collision

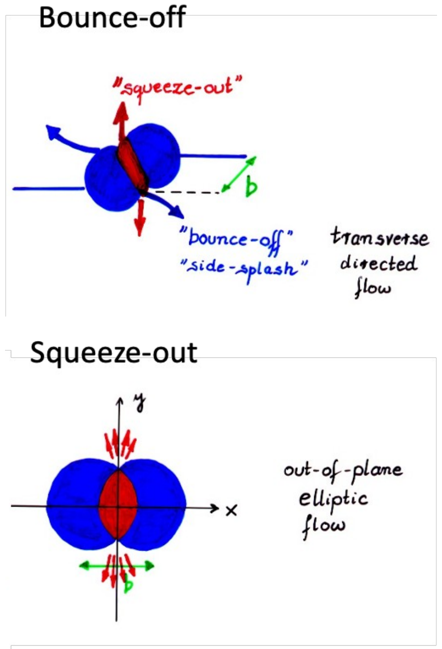
Important constrain for transport properties and EOS (η/s, ζ/s, etc.)

v_n of identified hadrons:

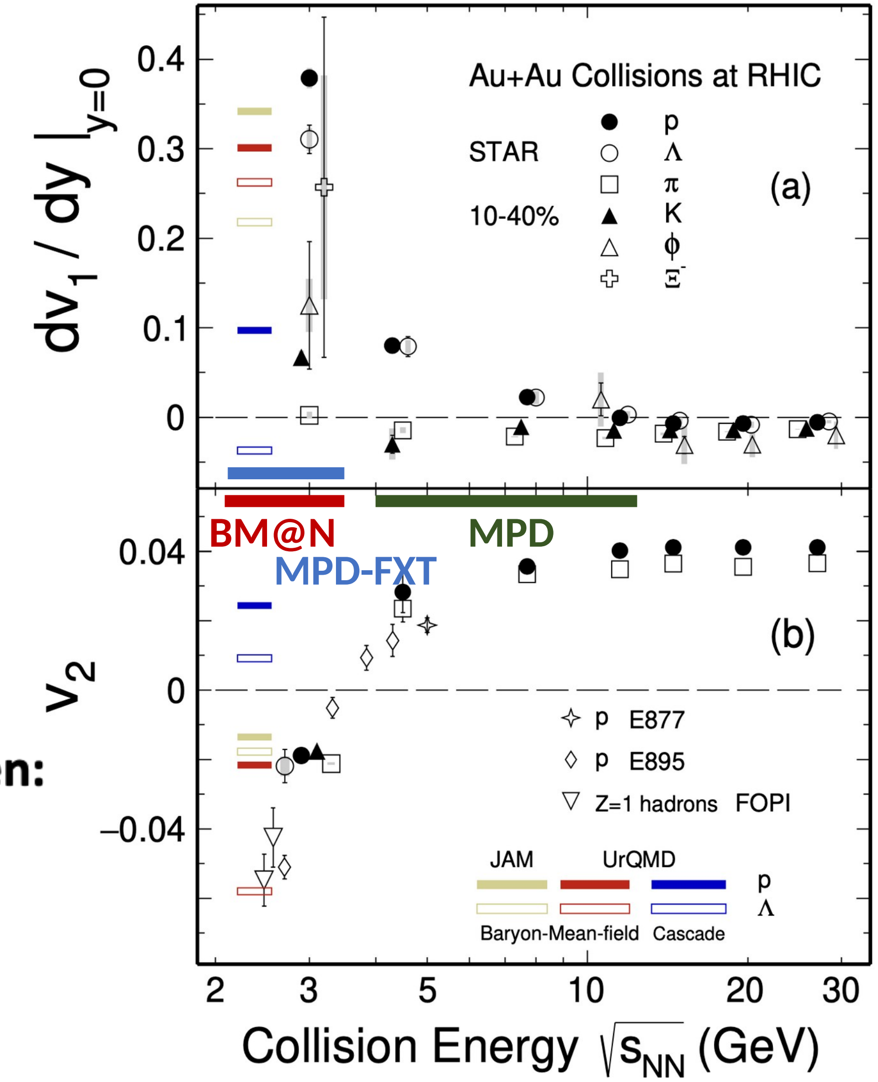
- **Mass ordering at p_T<2 GeV/c** (hydrodynamic flow, hadron rescattering)
- **Baryon/meson grouping at p_T>2 GeV/c** (recombination/coalescence) Number of constituent quark (NCQ) scaling

Anisotropic flow at Nuclotron-NICA energies





STAR, Phys.Lett.B 827 (2022) 137003



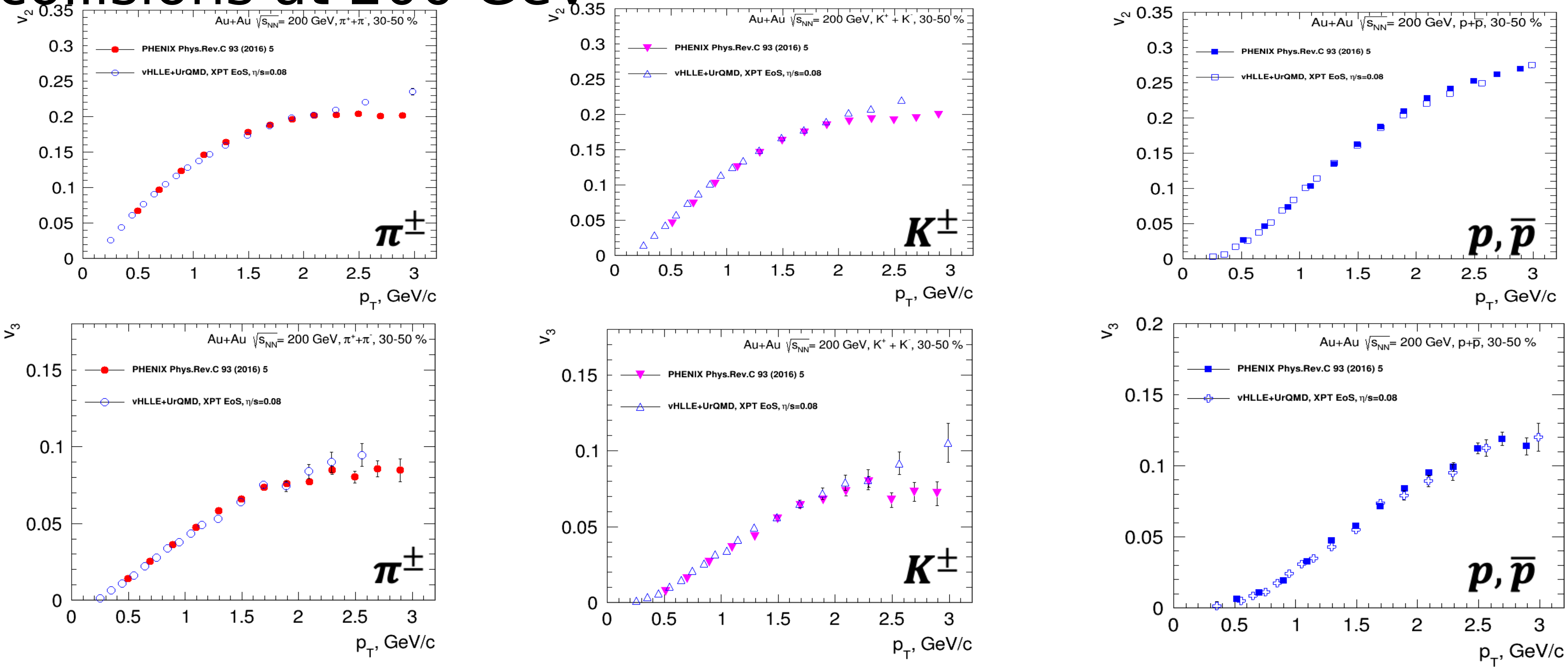
Strong energy dependence of dv_1/dy and v_2 at $\sqrt{s_{NN}}$=2-11 GeV

Anisotropic flow at Nuclotron-NICA energies is a delicate balance between:

I. The ability of pressure developed early in the reaction zone $(t_{exp} = R/c_s)$

II. The passage time for removal of the shadowing by spectators. $(t_{pass} = 2R/\gamma_{CM}\beta_{CM})$

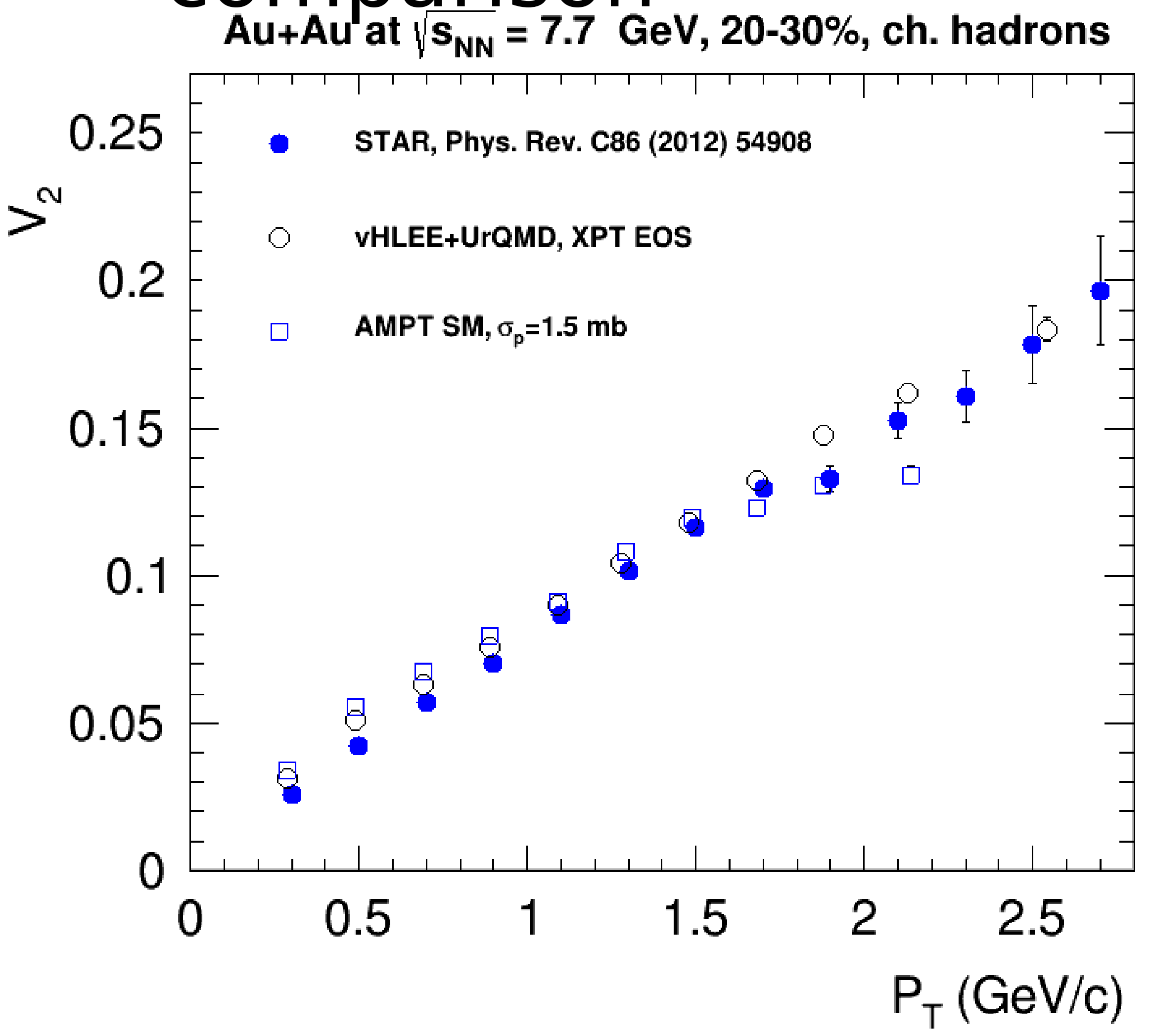
vHLLE+UrQMD: Elliptic and triangular flow in Au+Au collisions at 200 GeV

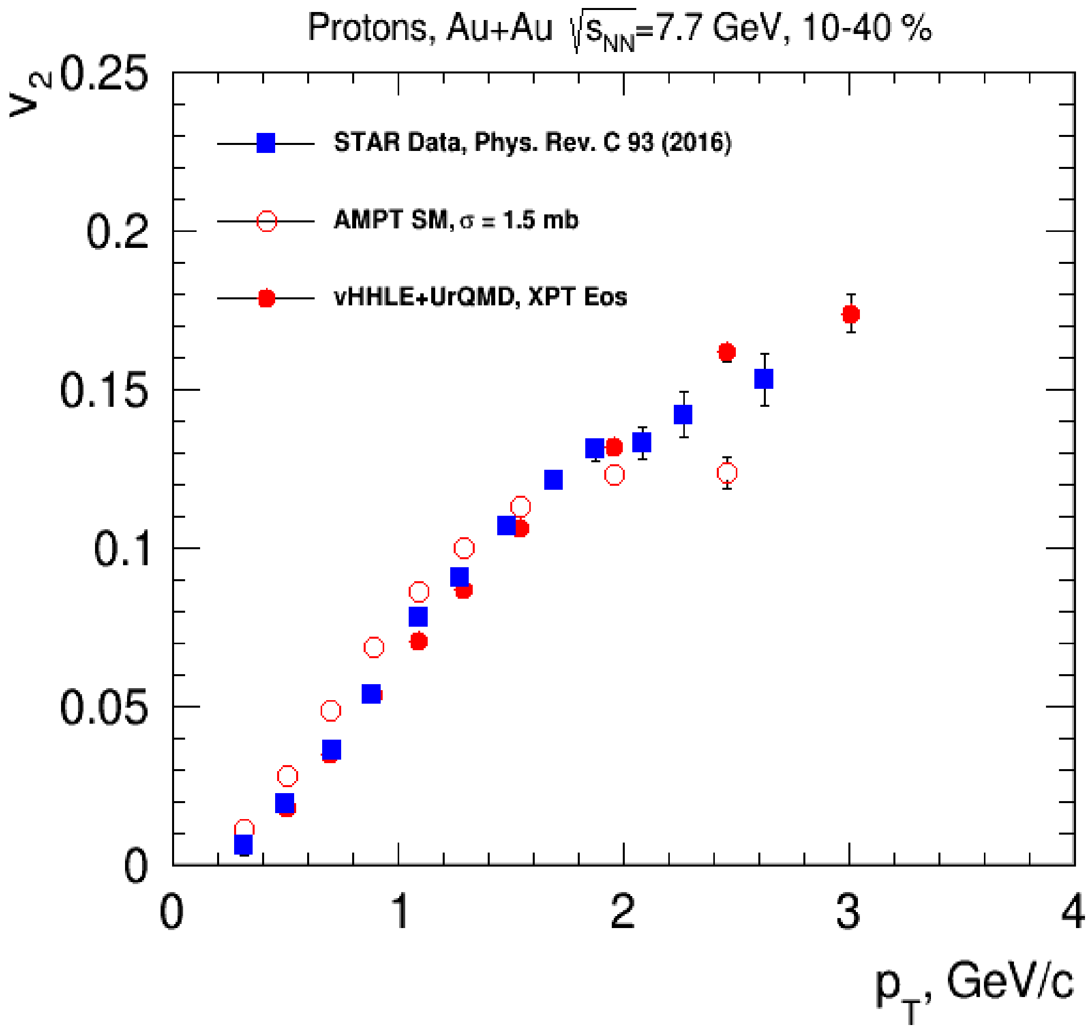


3D hydro model vHHLE + UrQMD (XPT EOS), η/s= 0.08 + param from Iu.A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher , Phys.Rev. C91 (2015) no.6, 064901

Reasonable agreement between results of vHLLE+UrQMD model and published PHENIX data

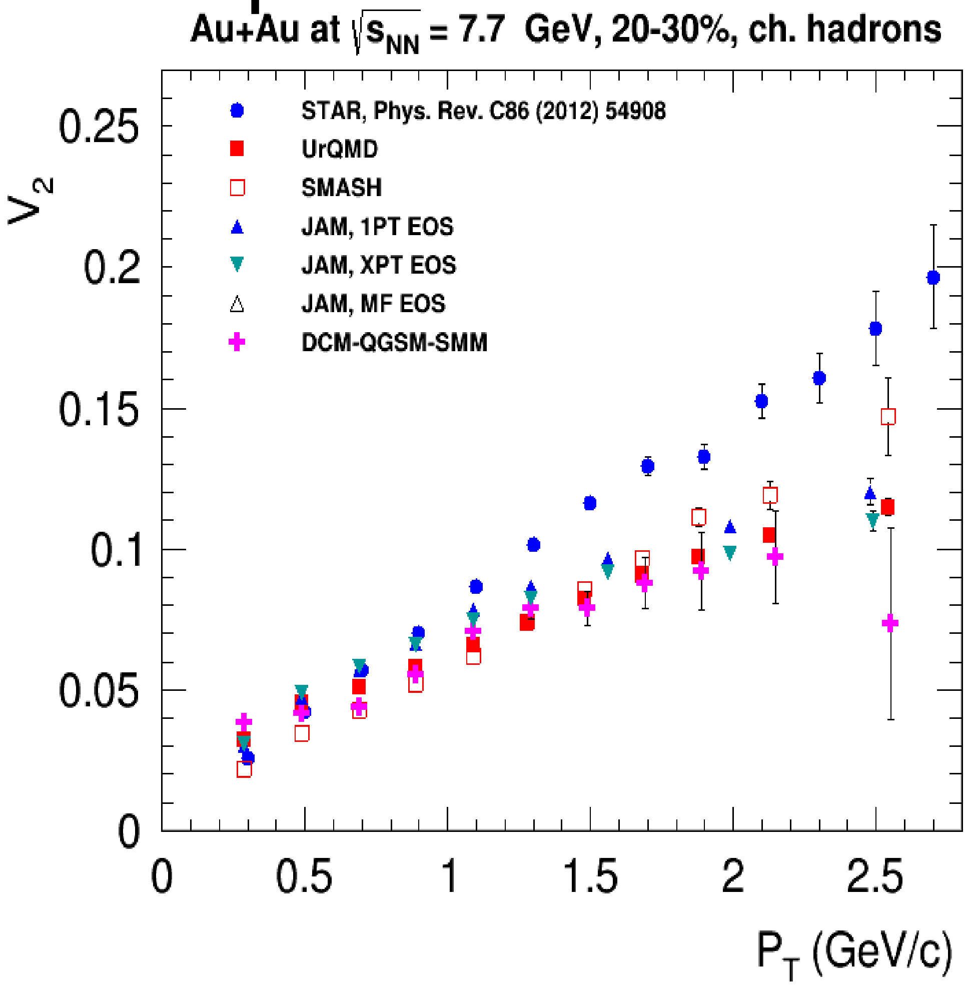
Elliptic flow at NICA energies: Models vs. Data comparison

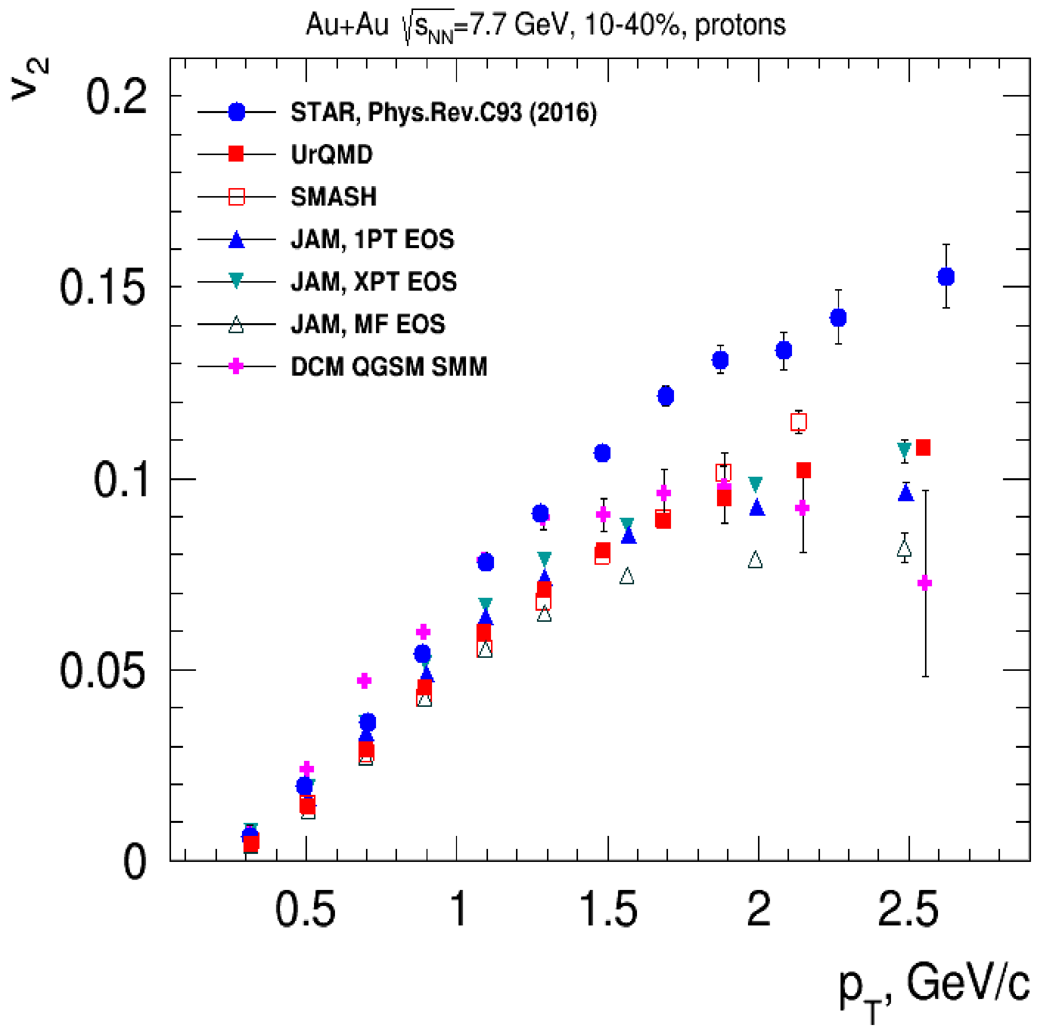




Good agreement between vHLLE+UrQMD (η/s= 0.2, XPT EOS), AMPT models and STAR data for $\sqrt{s_{NN}}$ ≥7.7 GeV

Elliptic flow at NICA energies: Models vs. Data comparison

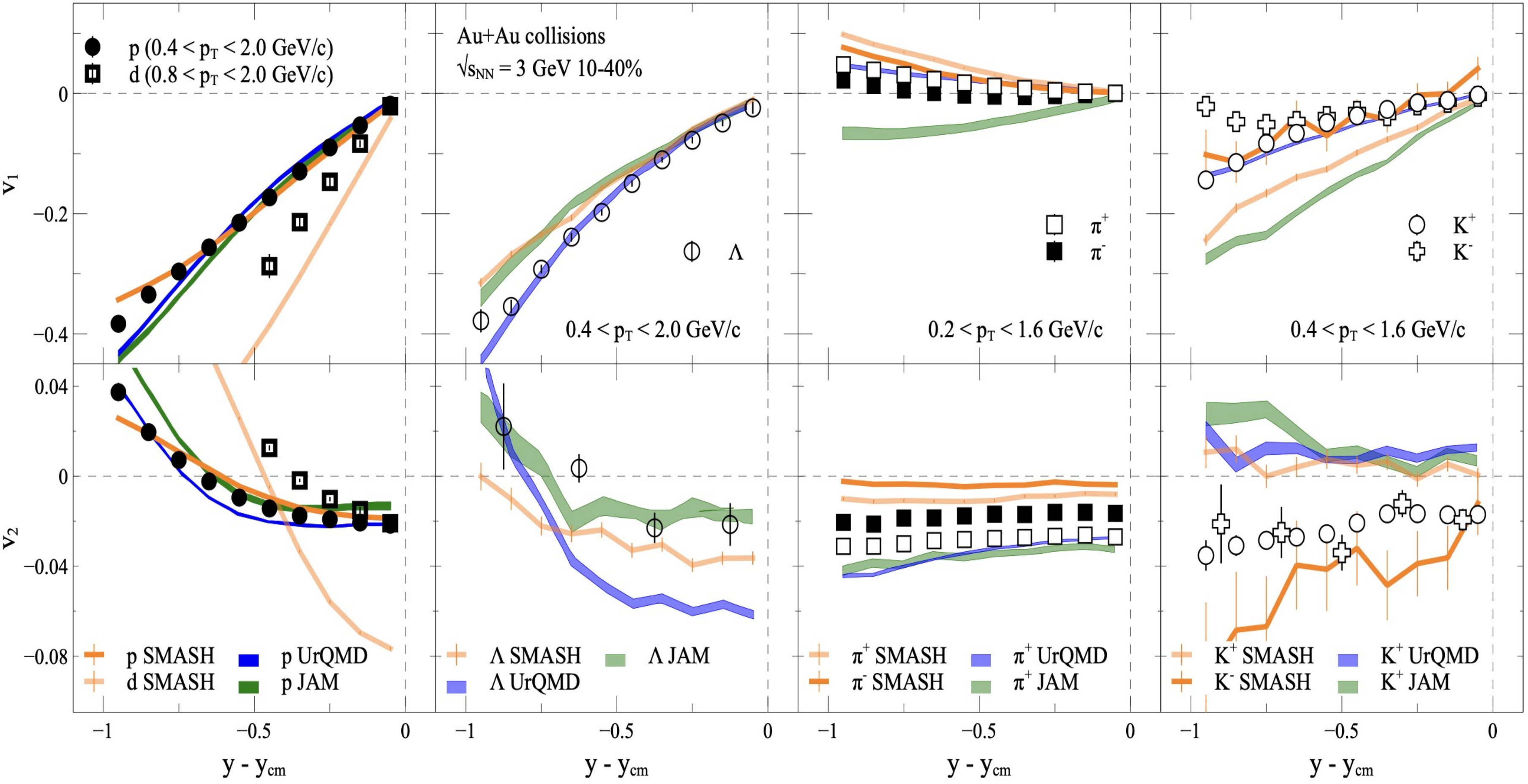




Pure String/Hadronic Cascade models give smaller v_2 signal compared to STAR data for $\sqrt{s_{NN}}$ ≥7.7 GeV

$v_{1,2}(y)$ in Au+Au $\sqrt{s_{NN}}$=3 GeV: model vs. STAR data

A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080



Model description of v_n:

- Good overall agreement for v_n of protons
- v_n of light nuclei is not described
- v_n of Λ is not well described
  - **nucleon-hyperon** and **hyperon-hyperon** interactions
- Light mesons (π,K) are not described
  - No mean-field for mesons

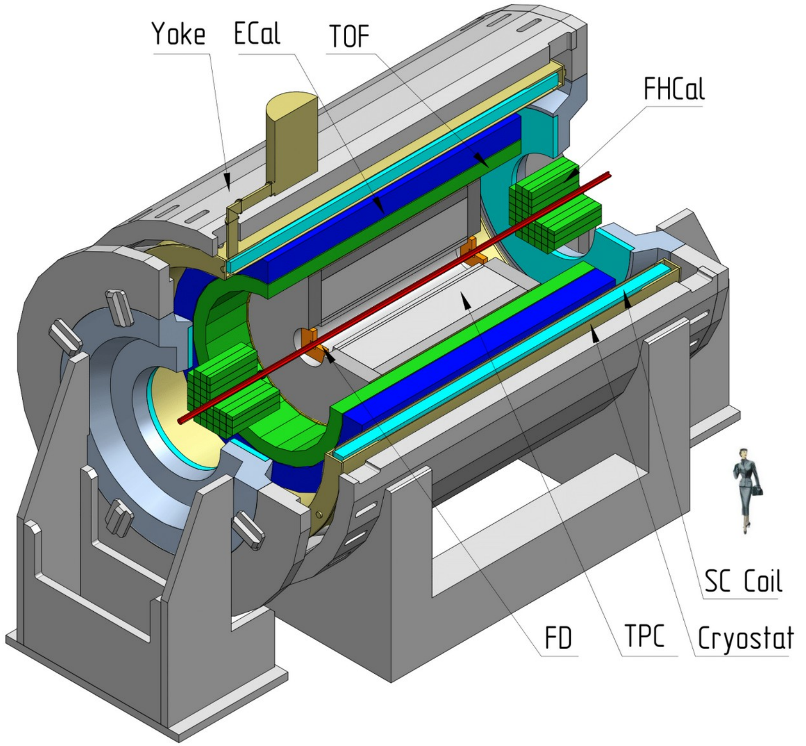
Models have a huge room for improvement in terms of describing v_n

MPD Experiment at NICA

UrQMD → GEANT4 → Reconstruction → Flow analysis

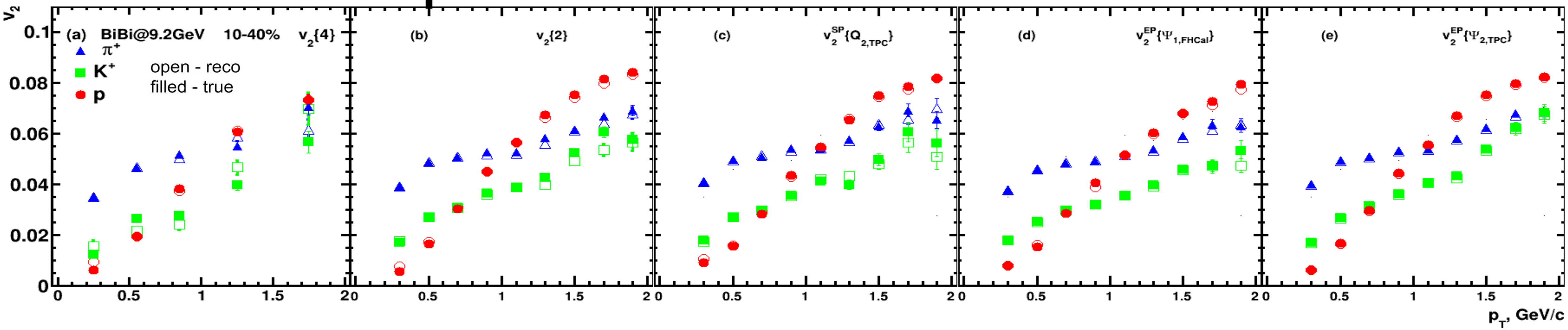
- Bi+Bi: 50M at $\sqrt{s_{NN}}$ = 9.2 GeV (UrQMD, vHLLE+UrQMD, ...)
- Centrality determination: Bayesian inversion method and MC-Glauber
- Event plane determination: TPC, FHCal
- Track selection:
  - Primary tracks
  - $N_{TPC\ hits} \geq 16$
  - $0.2 < p_T < 3.0$ GeV/c
  - $|\eta| < 1.5$
  - PID – ToF + dE/dx

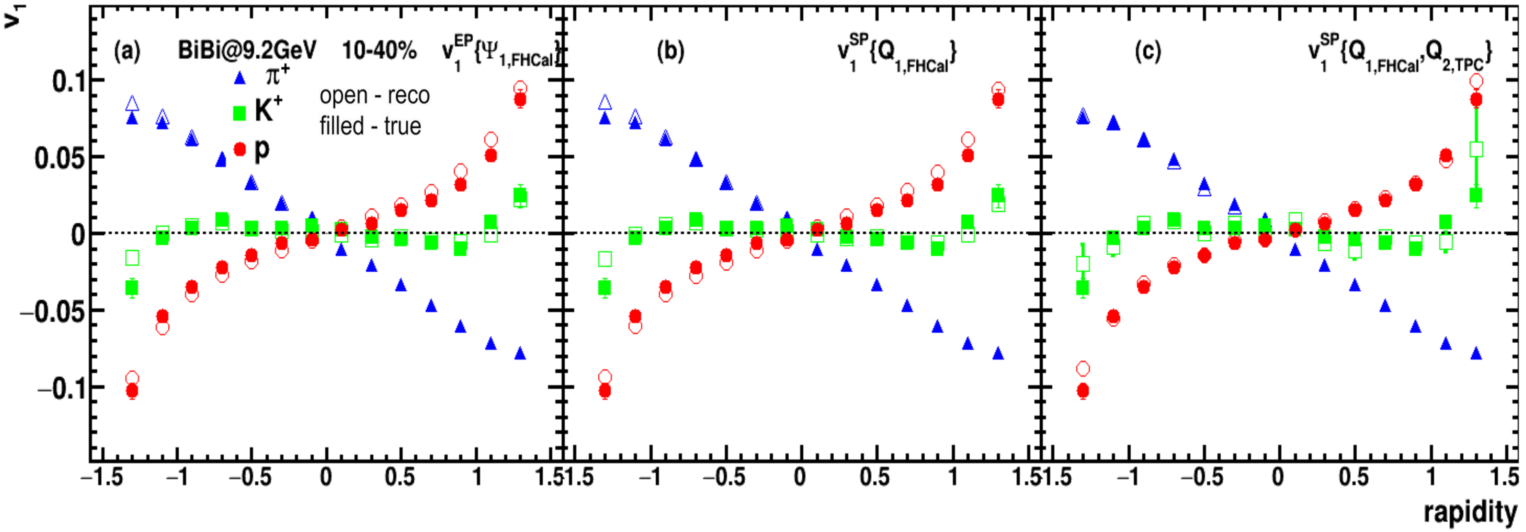
$-5<\eta<-2$	$-1.5<\eta<1.5$	$2<\eta<5$
FHCal	TPC $0.2<p_T<3$ GeV/c	FHCal



Multi-Purpose Detector in collider mode (MPD-CLD)

Anisotropic flow in MPD-CLD



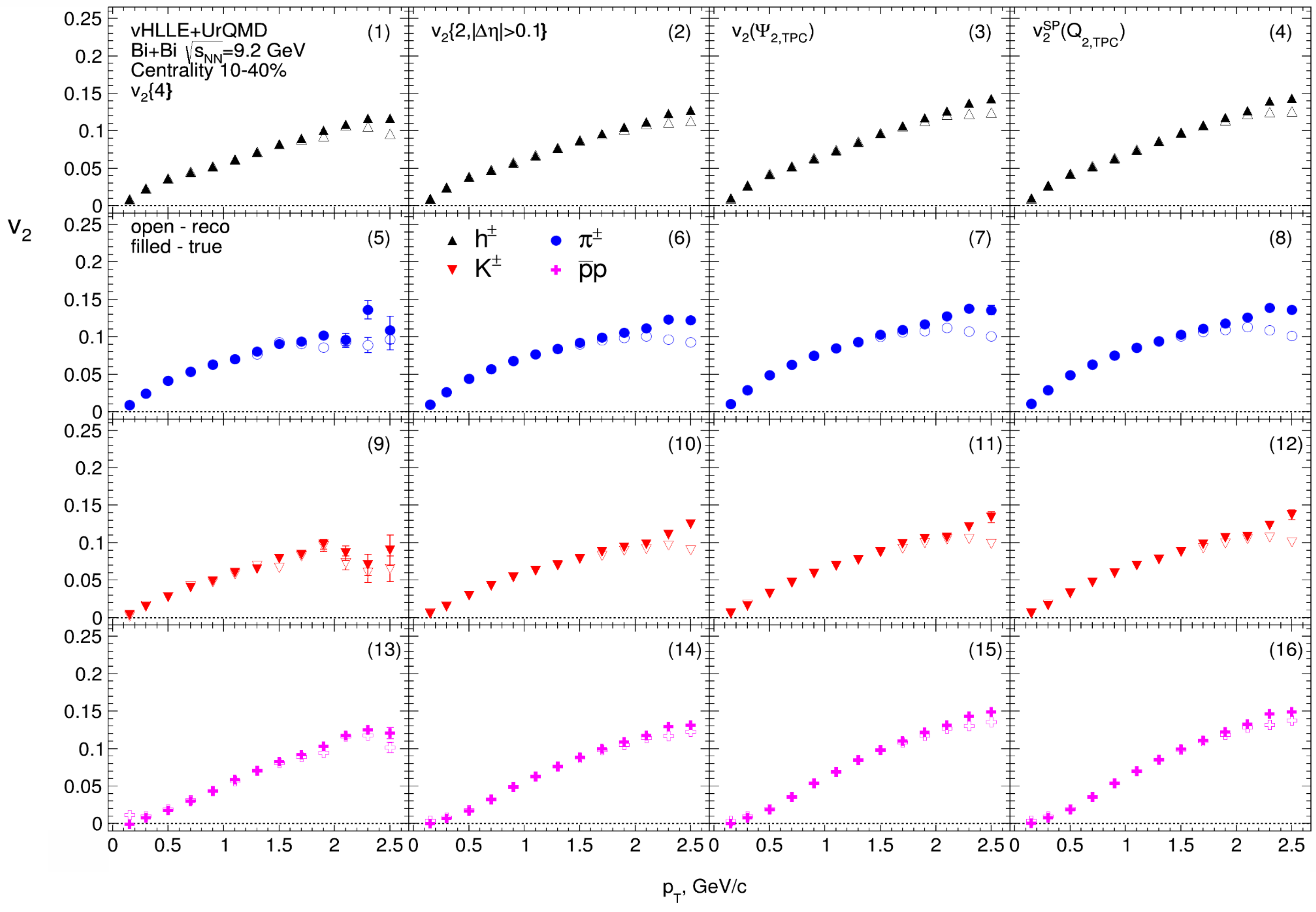


Extensive feasibility studies were done for the MPD-CLD:

- FHCal TDR: v_1 and v_2 using FHCal EP
- 1st collaboration paper: *Eur.Phys.J.A* 58 (2022) 7, 140
- v_1 performance: *Phys.Part.Nucl.* 52 (2021) 4, 618-623
- v_2 performance: *Phys.Part.Nucl.* 52 (2021) 4, 637-643
- Model study: *Particles* 5 (2022) 4, 561-579
- v_2 and its fluctuations: *Particles* 6 (2022) 1, 17-29
- v_2 fluctuations at NICA: *Phys.Part.Nucl.* 55 (2024) 4, 1124-1128

Good performance for flow measurements for all methods used (EP, SP, Q-cumulants)

Elliptic flow in MPD-CLD



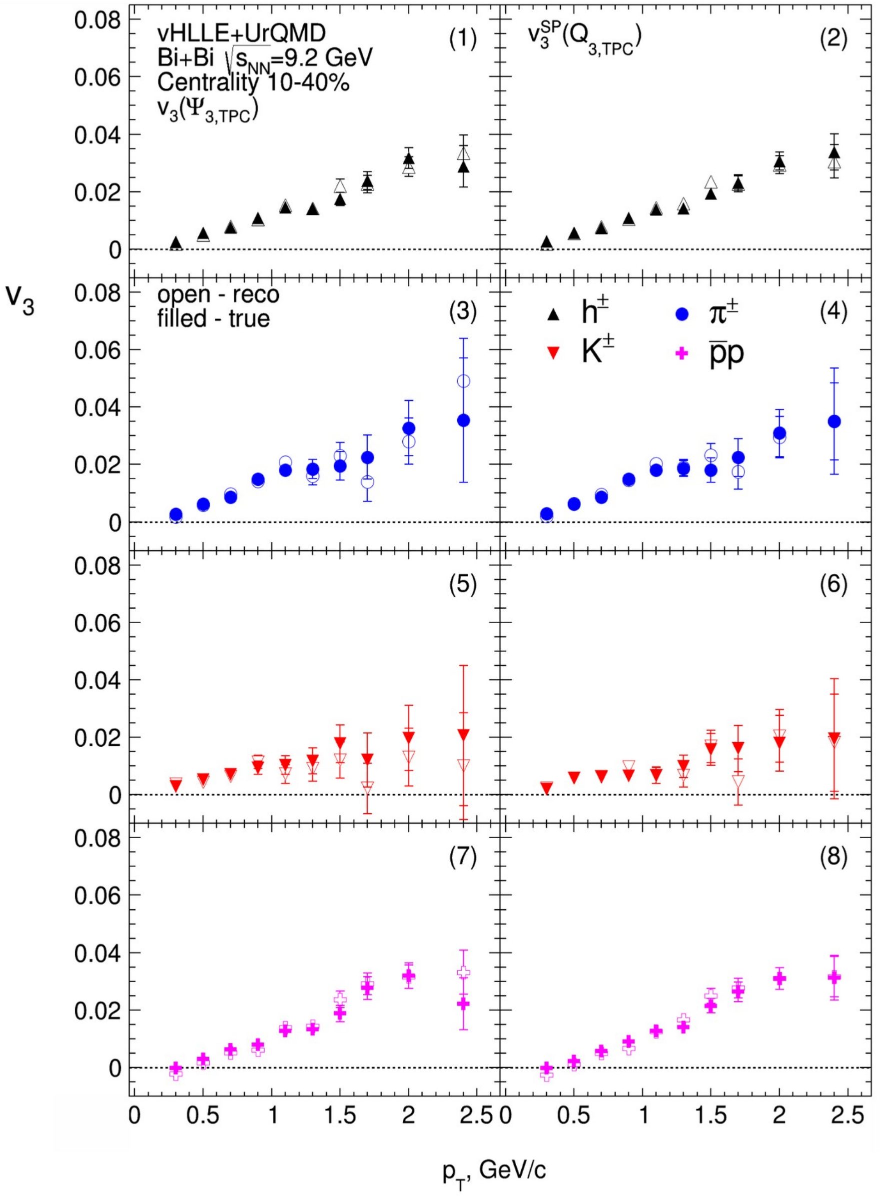
Cuts:

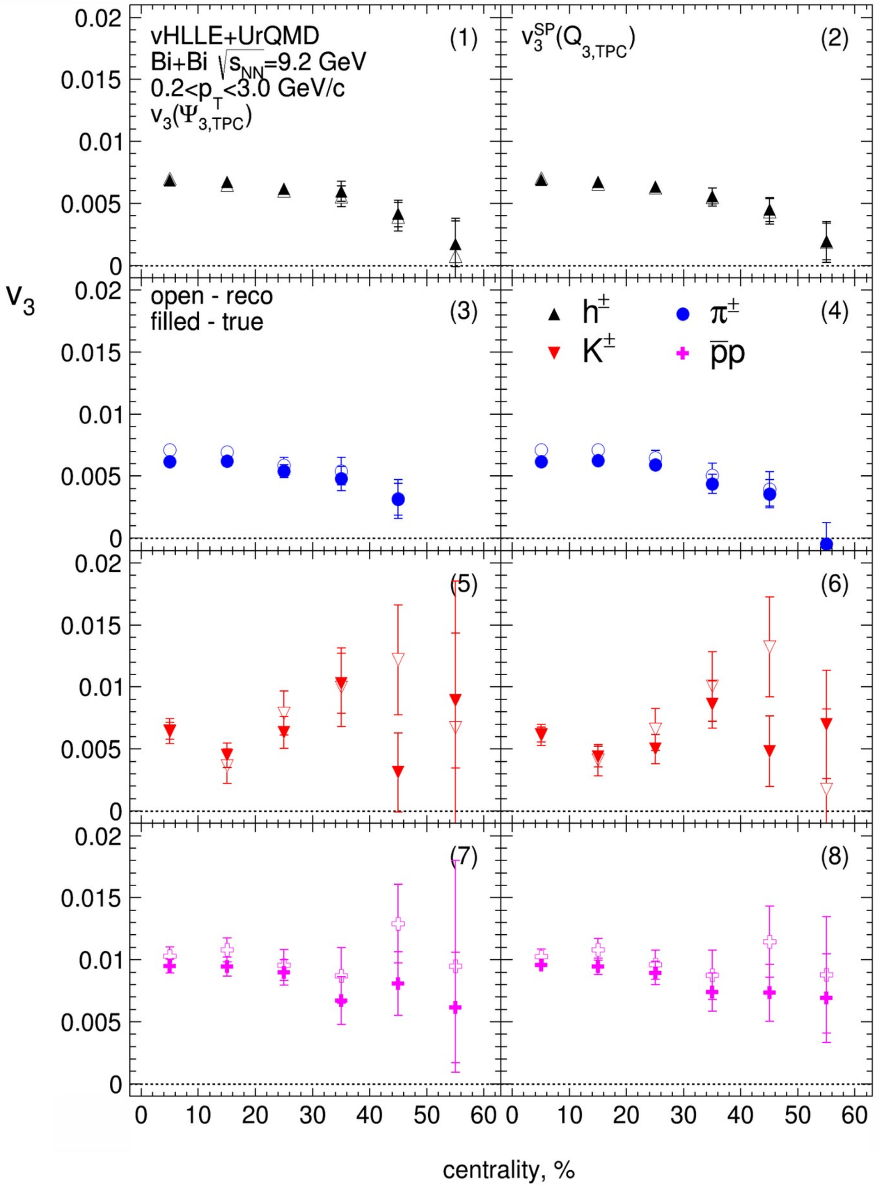
- Charged particles only
- Primary
- $|\eta|<1.5$
- $\Delta\,\eta$ = 0,1
- p_T >0.2 GeV/c
- $|DCA|<3\sigma$
- nTPC hits ≥ 16
- PID: PDG code

❑ good agreement of the $v_{2,mc}$ with $v_{2,reco}$ data

❑ The difference at large p_T between $v_{2,mc}$ and $v_{2,reco}$ (non-flow)

Triangular flow in MPD-CLD

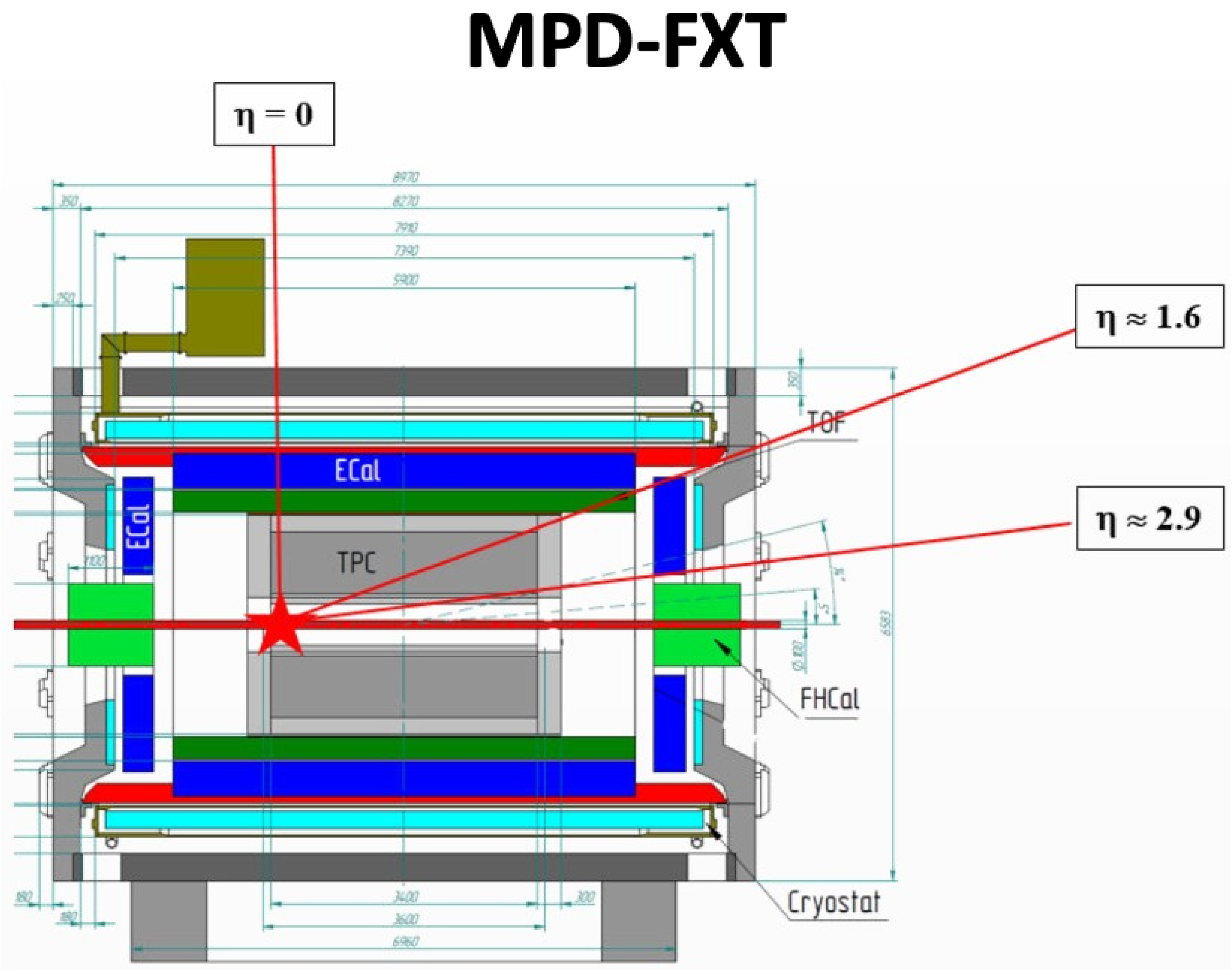




Cuts:

- Charged particles only
- Primary
- $|\eta|<1.5$
- $\Delta\eta = 0,1$
- $p_T > 0.2$ GeV/c
- $|DCA|<3\sigma$
- nTPC hits ≥ 16
- PID: PDG code

MPD in Fixed-Target Mode (FXT)



- Model used: UrQMD mean-field
  - Bi+Bi, E_{kin}=1.45 AGeV ($\sqrt{s_{NN}}$ =2.5 GeV)
  - Bi+Bi, E_{kin}=2.92 AGeV ($\sqrt{s_{NN}}$ =3.0 GeV)
  - Bi+Bi, E_{kin}=4.65 AGeV ($\sqrt{s_{NN}}$=3.5 GeV)
- Point-like target at z = -115 cm
- GEANT4 transport
- Multiplicity-based centrality determination
- PID using information from TPC and TOF
- Primary track selection: DCA<1 cm
- Track selection:
  - N_{hits}>27 (protons), N_{hits}>22 (pions)

The Bayesian inversion method (Γ-fit)

Relation between multiplicity N_{ch} and impact parameter b is defined by

the fluctuation kernel:

$$P(N_{ch}|c_b) = \frac{1}{\Gamma(k(c_b))\theta^k} N_{ch}^{k(c_b)-1} e^{-n/\theta} \qquad \frac{\sigma^2}{\langle N_{ch} \rangle} = \theta \simeq const,\ k = \frac{\langle N_{ch} \rangle}{\theta}$$

$c_b = \int_0^b P(b')db'$ – centrality based on impact parameter

Mean multiplicity as a function of c_b can be defined as follows:

$$\langle N_{ch} \rangle = N_{knee} \exp\left(\sum_{j=1}^{3} a_j c_b^j \right)$$

N_{knee}, θ, a_j - 5 parameters

Fit function for N_{ch} distribution:

$$P(N_{ch}) = \int_0^1 P(N_{ch}|c_b)dc_b$$

b-distribution for a given N_{ch} range:

$$P(b|n_1 < N_{ch} < n_2) = P(b)\frac{\int_{n_1}^{n_2} P\,(N_{ch}|b)dN_{ch}}{\int_{n_1}^{n_2} P\,(N_{ch})dN_{ch}}$$

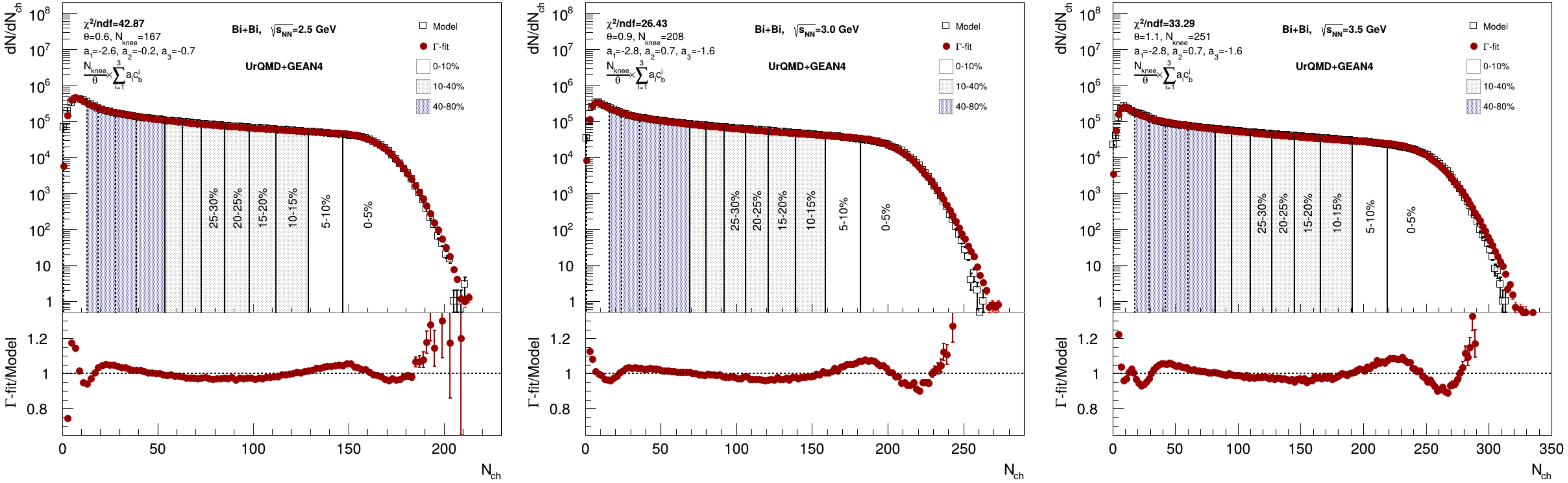
2 main steps of the method:

Fit experimental (model) distribution with P(N)

↓

Construct P(b|E) using Bayes' theorem:
P(b|N) = P(b)P(N|b)/P(N)

Centrality determination: multiplicity fit



Cuts on tracks:

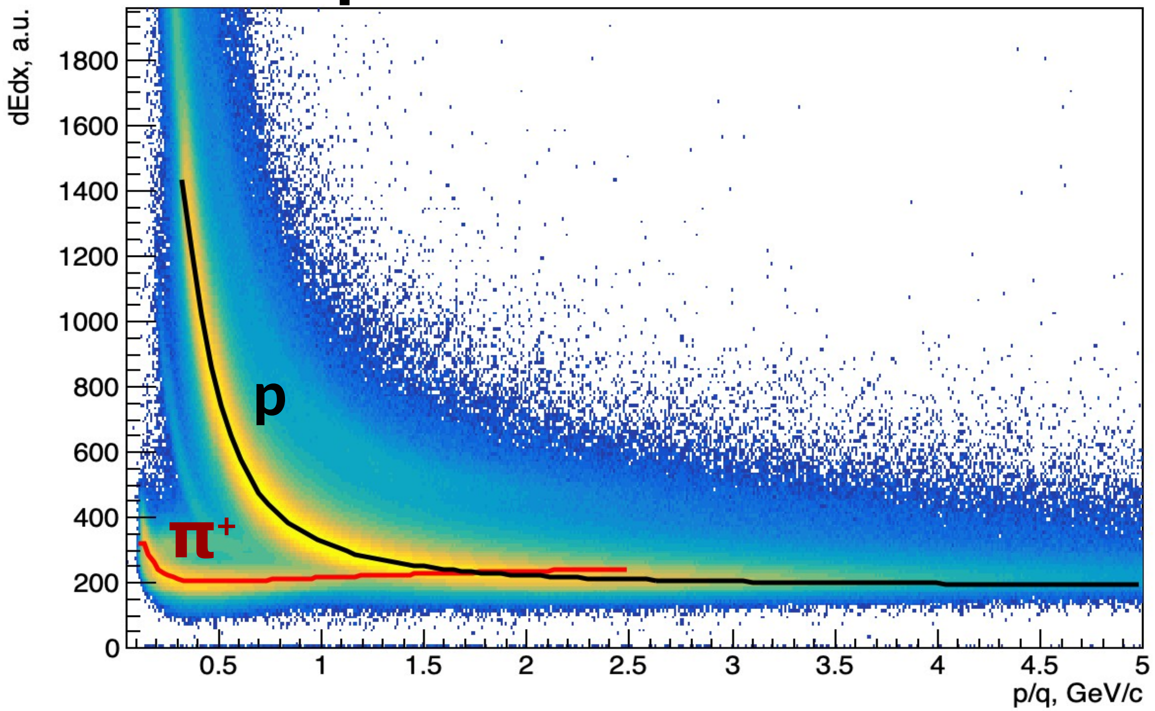
- Nhits>16
- 0 < η < 2

Good agreement between fit and data

Multiplicity-based centrality determination (Γ-fit) was used

PID procedure

W. Blum, W. Riegler, L. Rolandi, Particle Detection with Drift Chambers (2nd ed.), Springer, Verlag (2008)



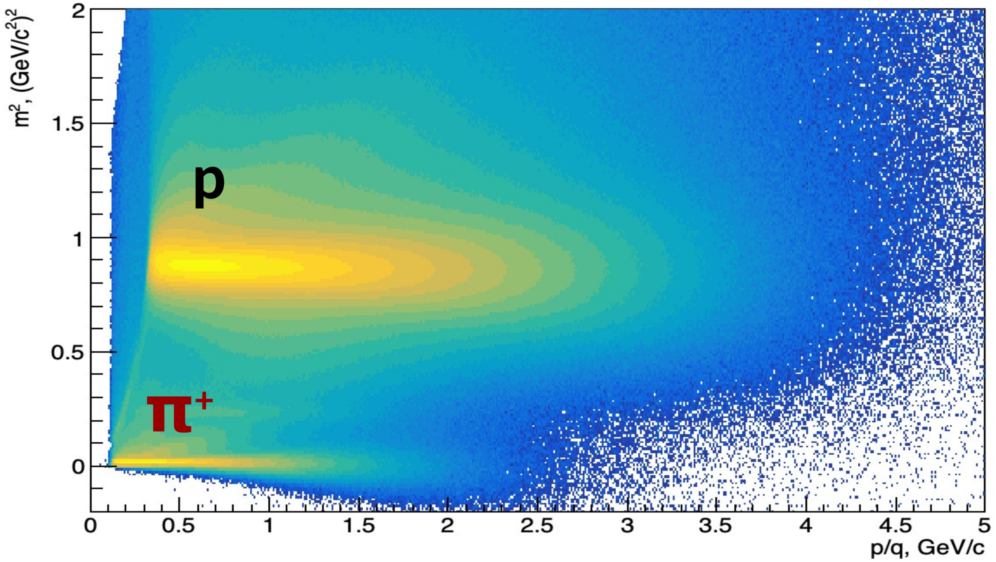
Fit dE/dx distributions with Bethe-Bloch parametrization:

$$f(\beta\gamma) = \frac{p_1}{\beta^{p_4}}\left(p_2 - \beta^{p_4} - \ln\left(p_3 + \frac{1}{(\beta\gamma)^{p_5}}\right)\right)$$

$$\beta^2 = \frac{p^2}{m^2+p^2},\ \beta\gamma = \frac{p}{m}$$

p_i - fit parameters

Fit $(dE/dx - f(\beta\gamma))/f(\beta\gamma)$ with gaus in the slices of p/q and get $\sigma_p(dE/dx)$

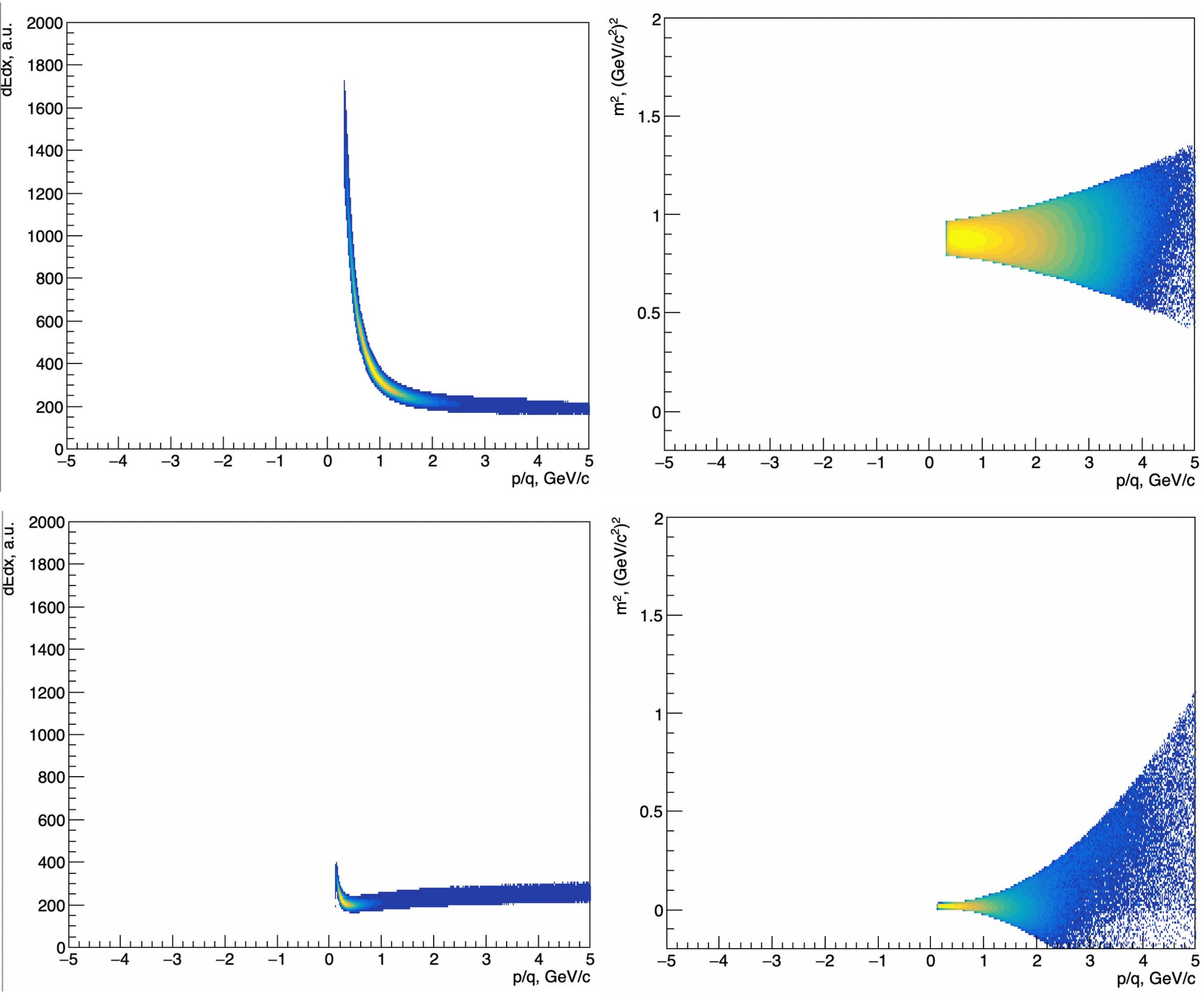


Fit m^2 with gaus in the slices of p/q and get $\sigma_p(m^2)$

(dE/dx,m)→(x,y) coordinates for PID:

$$x_p = \frac{(dE/dx)^{meas} - (dE/dx)_p^{fit}}{(dE/dx)_p^{fit}\sigma_p^{dE/dx}},\ \ y_p = \frac{m^2 - m_p^2}{\sigma_p^{m^2}}$$

PID procedure: Results



$$x_p = \frac{(dE/dx)^{meas} - (dE/dx)_p^{fit}}{(dE/dx)_p^{fit} \sigma_p^{dE/dx}}$$

$$y_p = \frac{m^2 - m_p^2}{\sigma_p^{m^2}}$$

Protons:

$$\sqrt{x_p^2 + y_p^2} < 2, \sqrt{x_\pi^2 + y_\pi^2} > 3$$

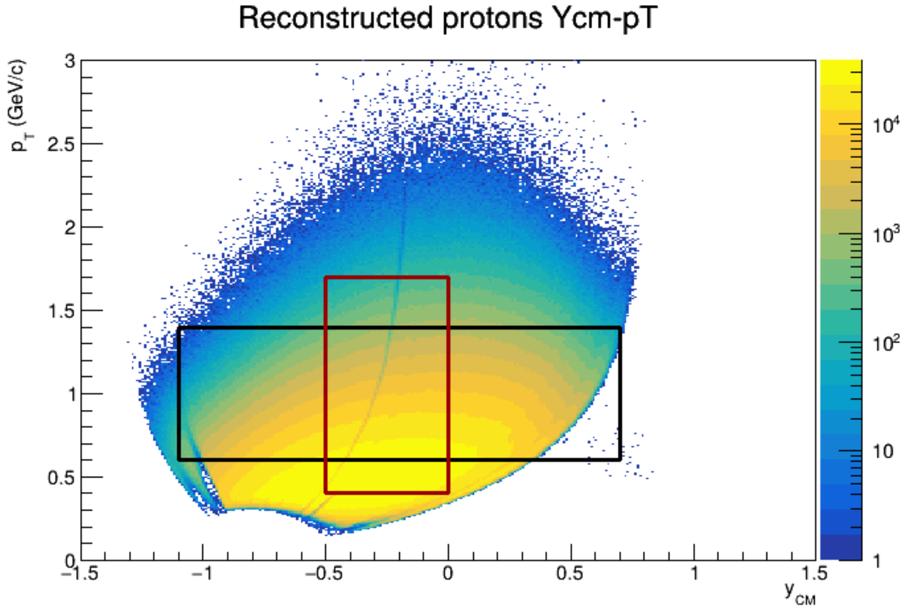
Pions (π^+):

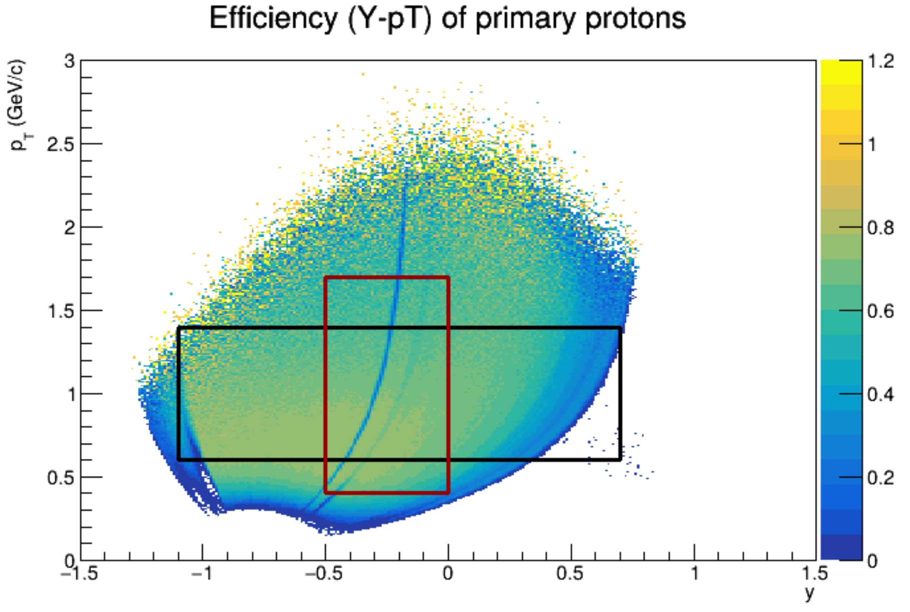
$$\sqrt{x_\pi^2 + y_\pi^2} < 2, \sqrt{x_p^2 + y_p^2} > 3$$

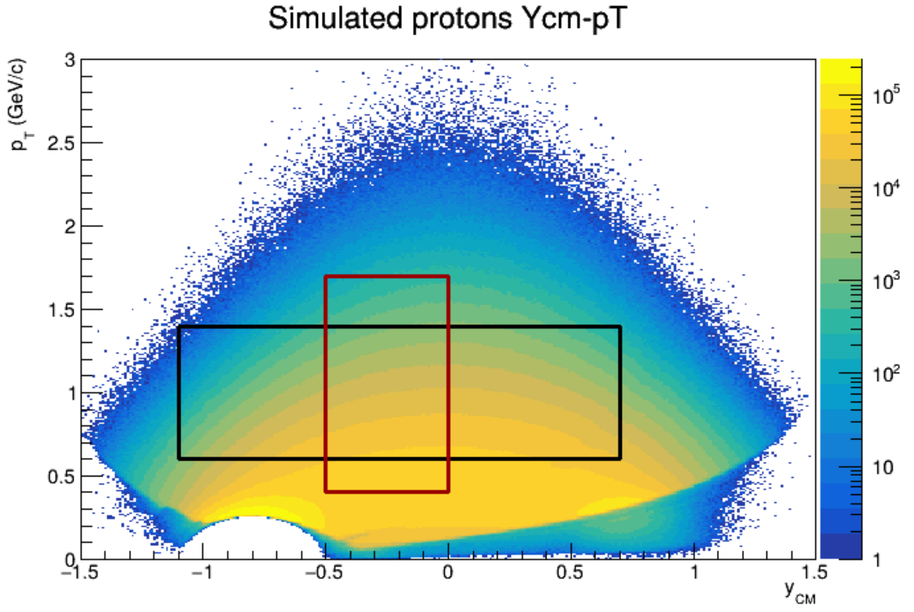
Pions (π^-):

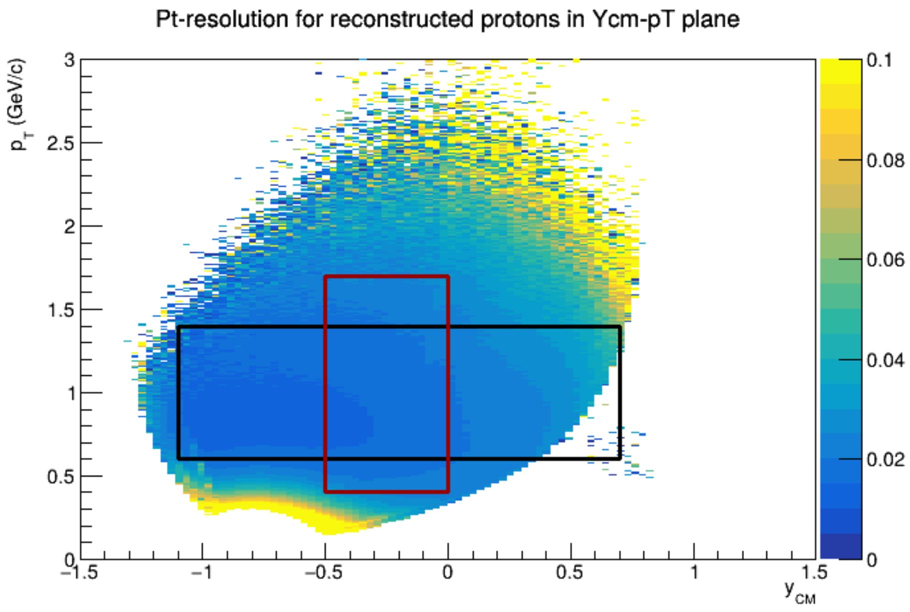
charge<0

(y-pt) distribution, efficiency and δpt (protons)









$$\mathrm{eff} = \frac{\frac{dN}{dydp_T}(\mathrm{reco})}{\frac{dN}{dydp_T}(\mathrm{sim})}$$

$$\Delta p_T = \frac{|p_T^{\mathrm{reco}} - p_T^{\mathrm{mc}}|}{p_T^{\mathrm{mc}}}$$

Bi+Bi $\sqrt{s_{NN}}$=2.5 GeV

Cuts for reco tracks:

- Nhits>27
- DCA< 1 cm
- PID (TPC+TOF)
- Primary (DCA<1 cm)

Cuts for sim particles:

- PID (pdg code)
- Primary (motherId)

Black box: acceptance window for $v_n(y)$

Red box: acceptance window for $v_n(p_T)$

Flow vectors

From momentum of each measured particle define a u_n-vector in transverse plane:

$$u_n = e^{in\phi}$$

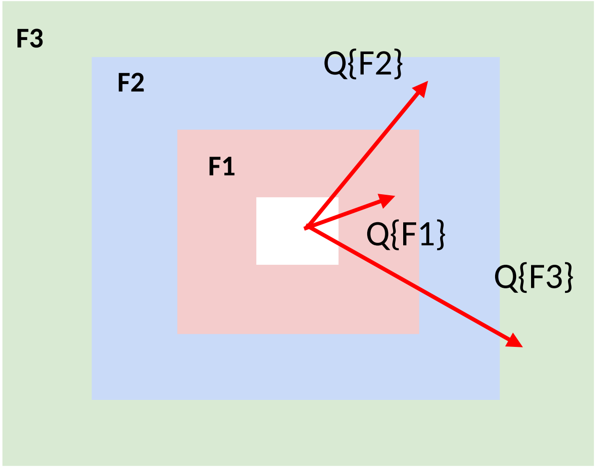
where φ is the azimuthal angle

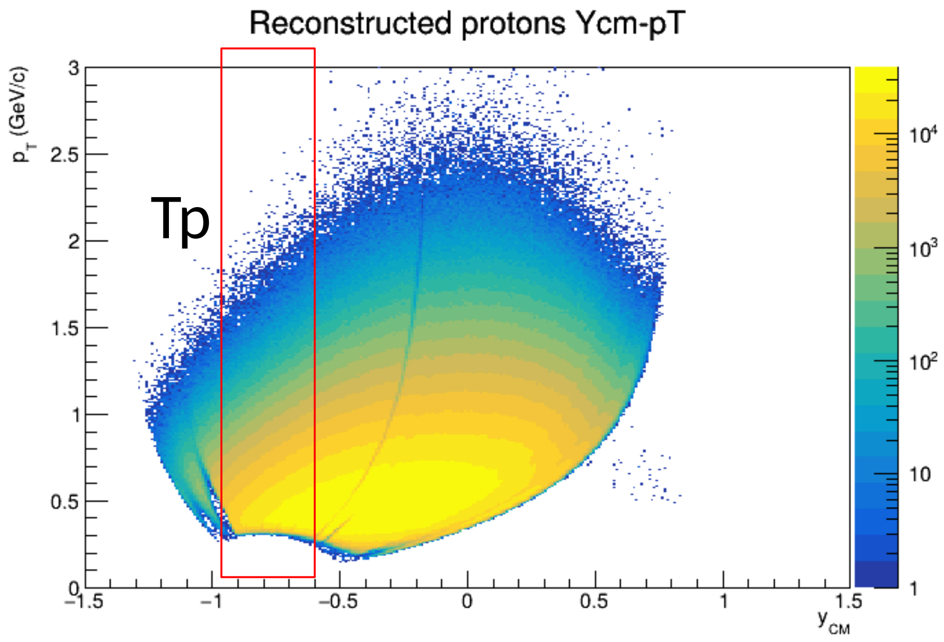
Sum over a group of u_n-vectors in one event forms Q_n-vector:

$$Q_n = \frac{\sum_{k=1}^{N} w_n^k u_n^k}{\sum_{k=1}^{N} w_n^k} = |Q_n| e^{in\Psi_n^{EP}}$$

Ψ_n^{EP} is the event plane angle

Modules of FHCal divided into 3 groups

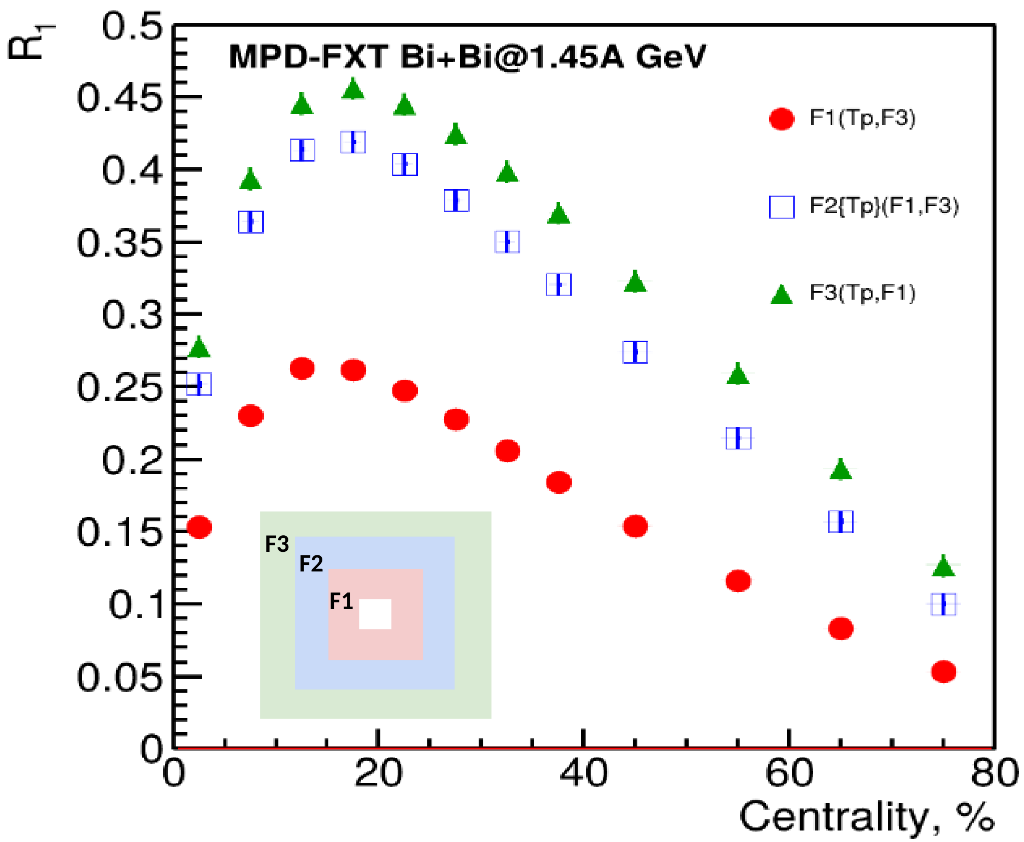




Additional subevents from tracks not pointing at FHCal:
Tp: p; -1.0<y<-0.6;

Flow methods for v_n calc

Tested in HADES: M Mamaev et al 2020 PPNuclei 53, 277–281
M Mamaev et al 2020 J. Phys.: Conf. Ser. 1690 012122



Scalar product (SP) method:

$$v_1 = \frac{\langle u_1 Q_1^{F1} \rangle}{R_1^{F1}} \qquad v_2 = \frac{\langle u_2 Q_1^{F1} Q_1^{F3} \rangle}{R_1^{F1} R_1^{F3}}$$

Where R_1 is the resolution correction factor

$$R_1^{F1} = \langle \cos(\Psi_1^{F1} - \Psi_1^{RP}) \rangle$$

Symbol "F2(F1,F3)" means R_1 calculated via (3S resolution):

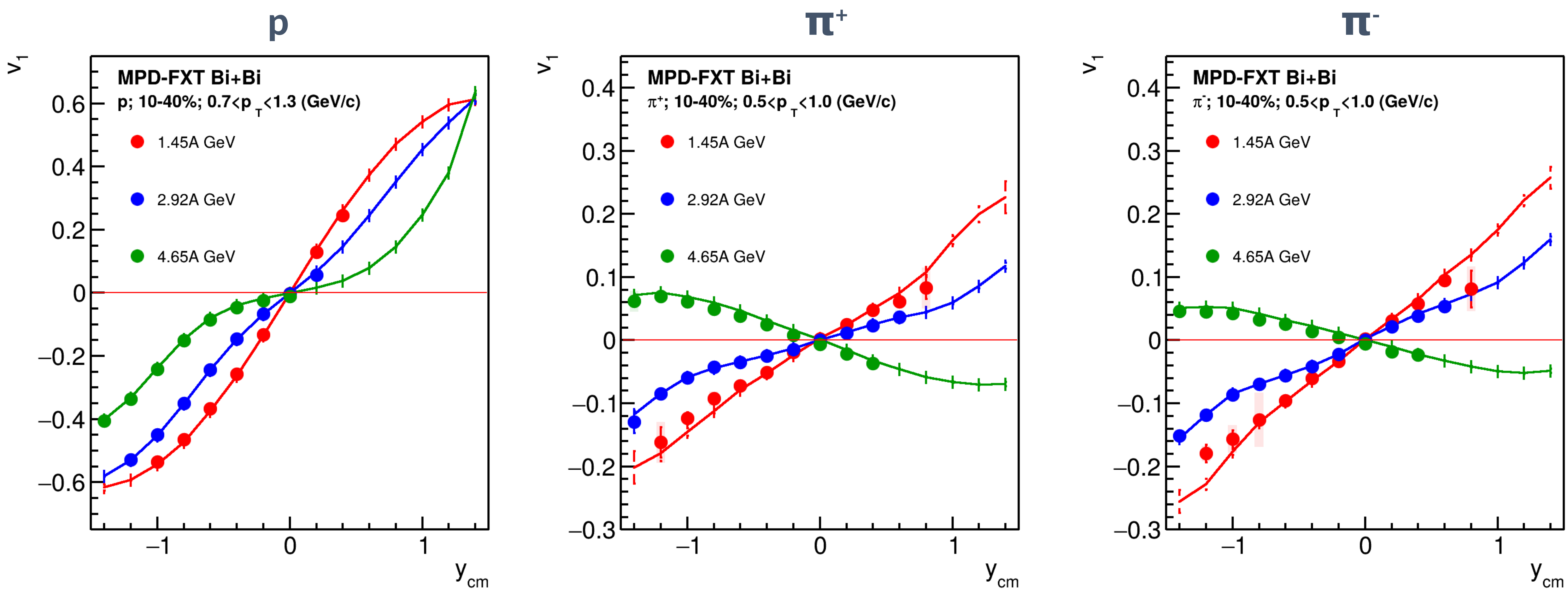
$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

Symbol "F2{Tp}(F1,F3)" means R_1 calculated via (4S resolution):

$$R_1^{F2\{Tp\}(F1,F3)} = \langle Q_1^{F2} Q_1^{Tp} \rangle \frac{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{Tp} Q_1^{F1} \rangle \langle Q_1^{Tp} Q_1^{F3} \rangle}}$$

Results: $v_1(y)$

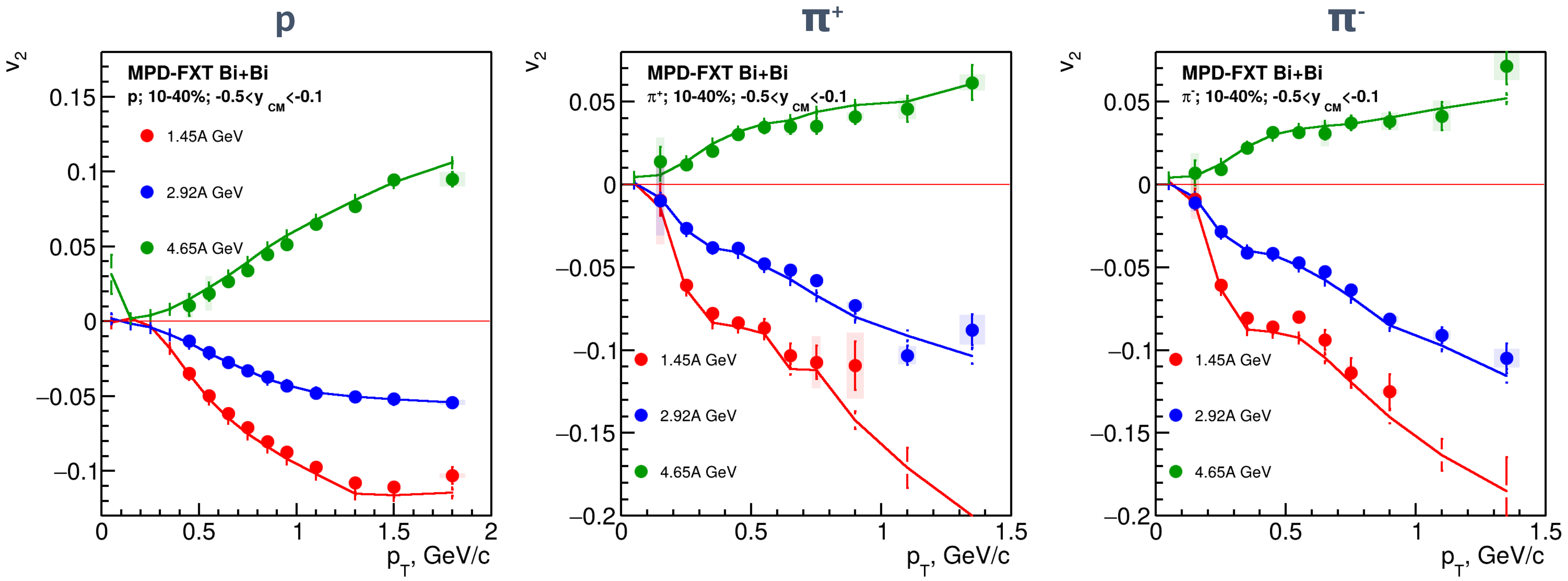
Systematics: xx, yy, F1, F2, F3



Good agreement with MC data

Results: $v_2(p_T)$

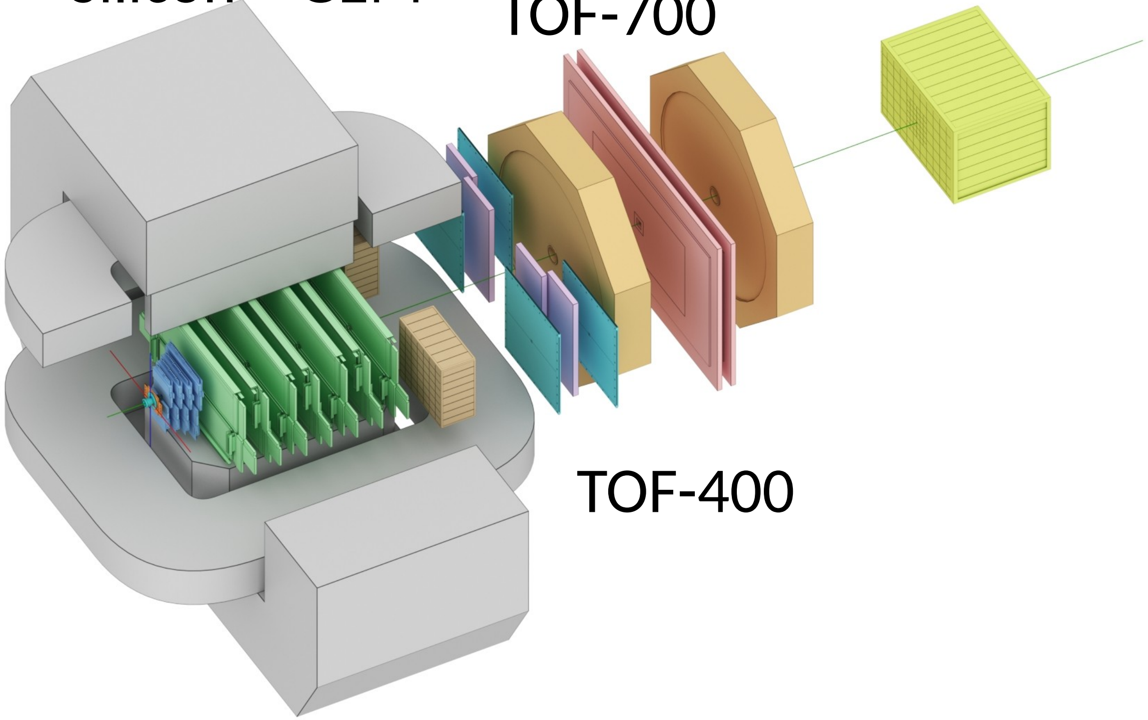
Systematics: xxx, xyy



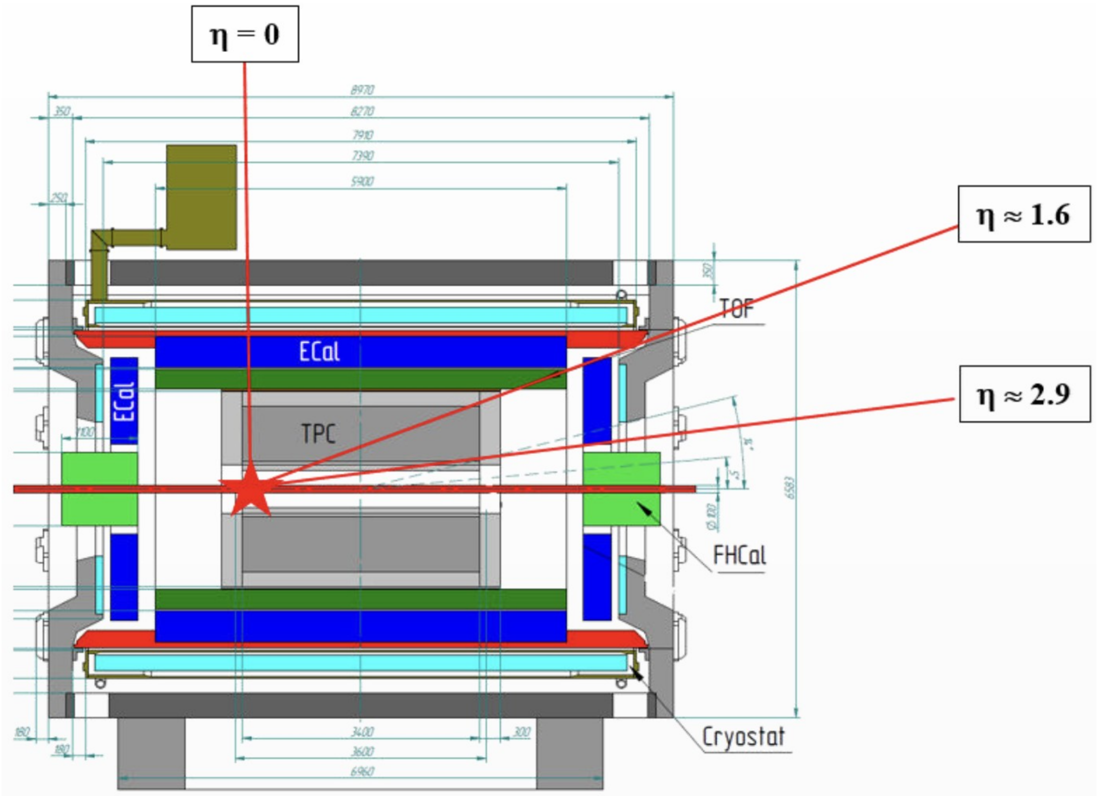
Good agreement with MC data

The BM@N and MPD-FXT experiments

BM@N



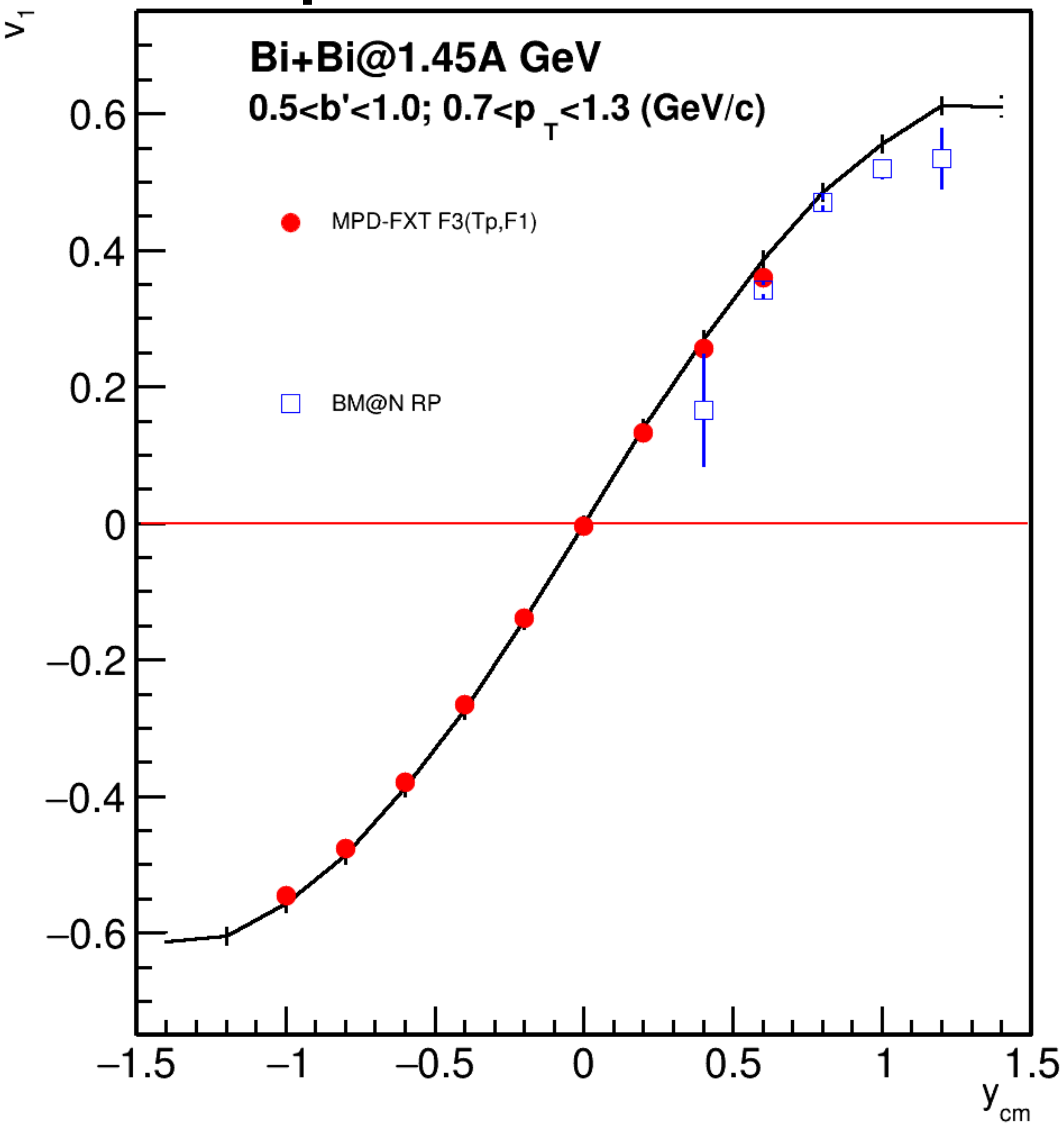
MPD-FXT



Detectors used for anisotropic flow measurements:

- **Tracking system:** FSD+GEM (BM@N); TPC (MPD-FXT)
- **PID:** TOF-400, TOF-700 (BM@N); TPC, TOF (MPD-FXT)
- **EP measurements:** FHCal (BM@N), FHCal (MPD-FXT)

Comparison with BM@N performance



BM@N TOF system (TOF-400 and TOF-700) has poor midrapidity coverage at $\sqrt{s_{NN}}$ = 2.5 GeV

- One needs to check higher energies ($\sqrt{s_{NN}}$ = 3, 3.5 GeV)
- More statistics are required due to the effects of magnetic field in BM@N:
  - Only “yy” component of <uQ> and <QQ> correlation can be used

Despite the challenges, both MPD-FXT and BM@N can be used in v_n measurements:

- To widen rapidity coverage
- To perform a cross-check in the future

Summary

- **Strong energy dependence of v_n at Nuclotron-NICA energy range**
  - Big passing times → spectators influences flow formation
  - **v_n at $\sqrt{s_{NN}}$>7.7 GeV:** models with QGP
  - **v_n at $\sqrt{s_{NN}}$<7.7 GeV:** models without QGP (cascade or mean-field models)
- **Performance study for the anisotropic flow measurements was shown for the MPD-FXT using realistic procedures for centrality determination, primary track selection and PID:**
  - Multiplicity-based centrality determination using Γ-fit shows good agreement between fit and data
  - Overall good agreement between the estimated fit and impact parameter with the corresponding values taken directly from the model
  - Basic PID was performed using dE/dx from TPC and m^2 from TOF
- **Directed and elliptic flow of protons and pions were measured for $\sqrt{s_{NN}}$ = 2.5, 3, 3.5 GeV:**
  - Good agreement between reconstructed and model data within corresponding acceptance windows for all particle species
- **Both MPD-FXT and BM@N can complement each other in terms of v_n:**
  - Cross-checks can be performed to test the implemented flow measurement techniques
  - Using results from both experiments can widen the rapidity coverage - **no single fixed target experiment can achieve that!**

New data from the BM@N and MPD (MPD-FXT) is required to address existing discrepancies in the experimental data and provide further constraints for the EoS in the models

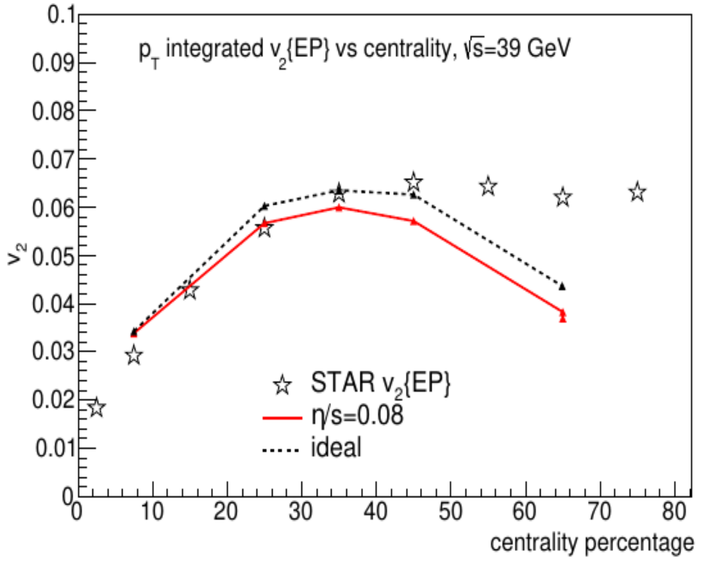
Backup

Hybrid models for anisotropic flow at RHIC/LHC

1. UrQMD + 3D viscous hydro model vHLLE+UrQMD

Iurii Karpenko, Comput. Phys. Commun. 185 (2014), 3016
https://github.com/yukarpenko/vhlle
Parameters: from Iu. A. Karpenko, P. Huovinen, H. Petersen, M. Bleicher, Phys. Rev. C91 (2015) no.6, 064901 – good description of STAR BES results for v_2 of inclusive charged hadrons (7.7-62.4 GeV)

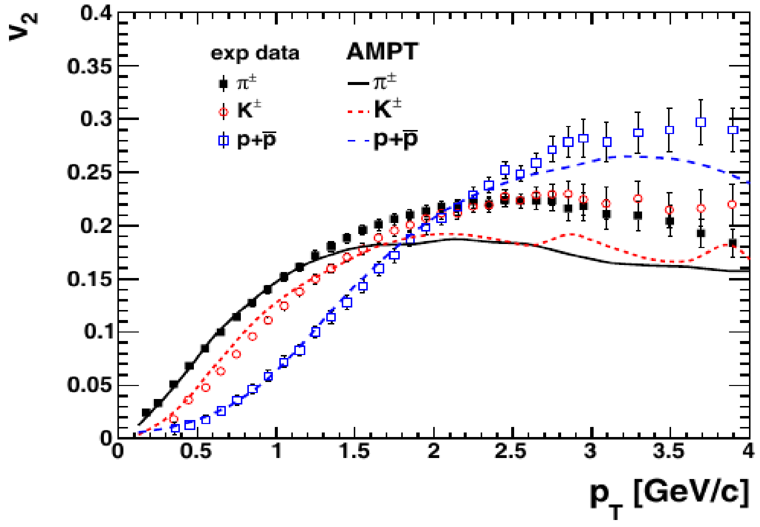
Initial conditions: model UrQMD
QGP phase: 3D viscous hydro (vHLLE) with crossover EOS (XPT)
Hadronic phase: model UrQMD



2. A Multi-Phase Transport model (AMPT) for high-energy nuclear collisions

The main source code (Zi-Wei Lin):
https://myweb.ecu.edu/linz/ampt/v1.26t9b/v2.26t9b

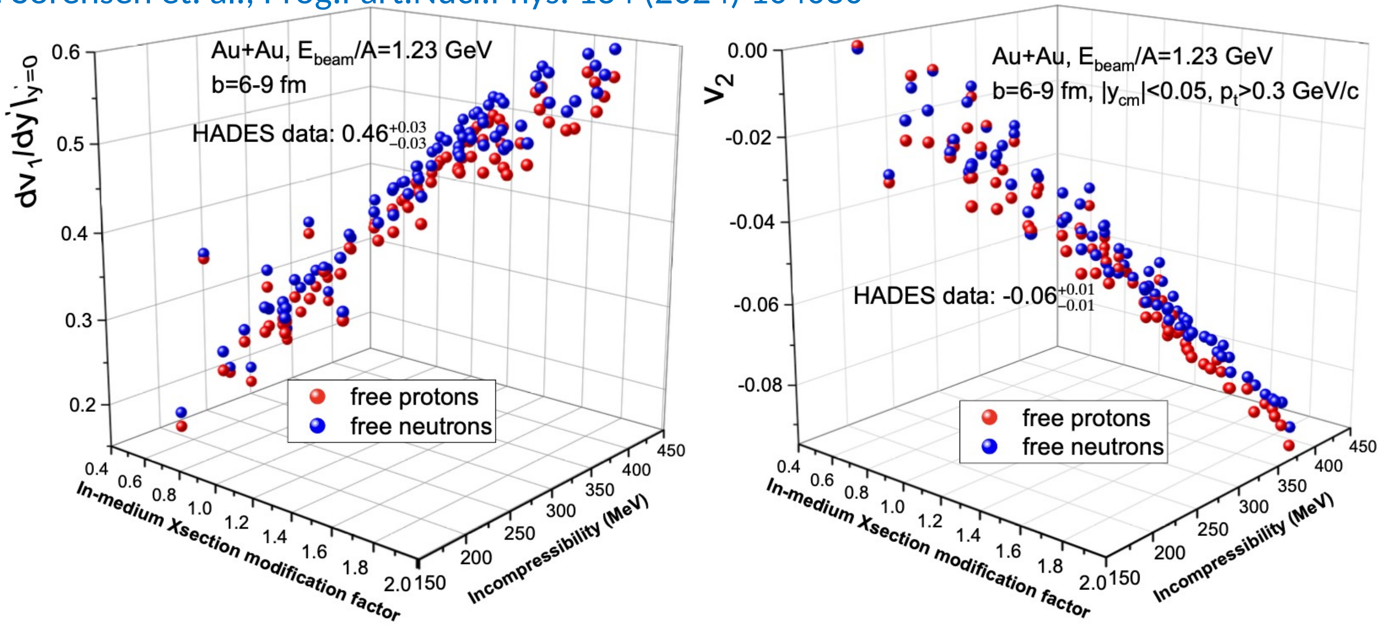
Initial conditions: model HIJING
QGP phase: Zhang's parton cascade for modeling partonic scatterings
Hadronic phase: model ART



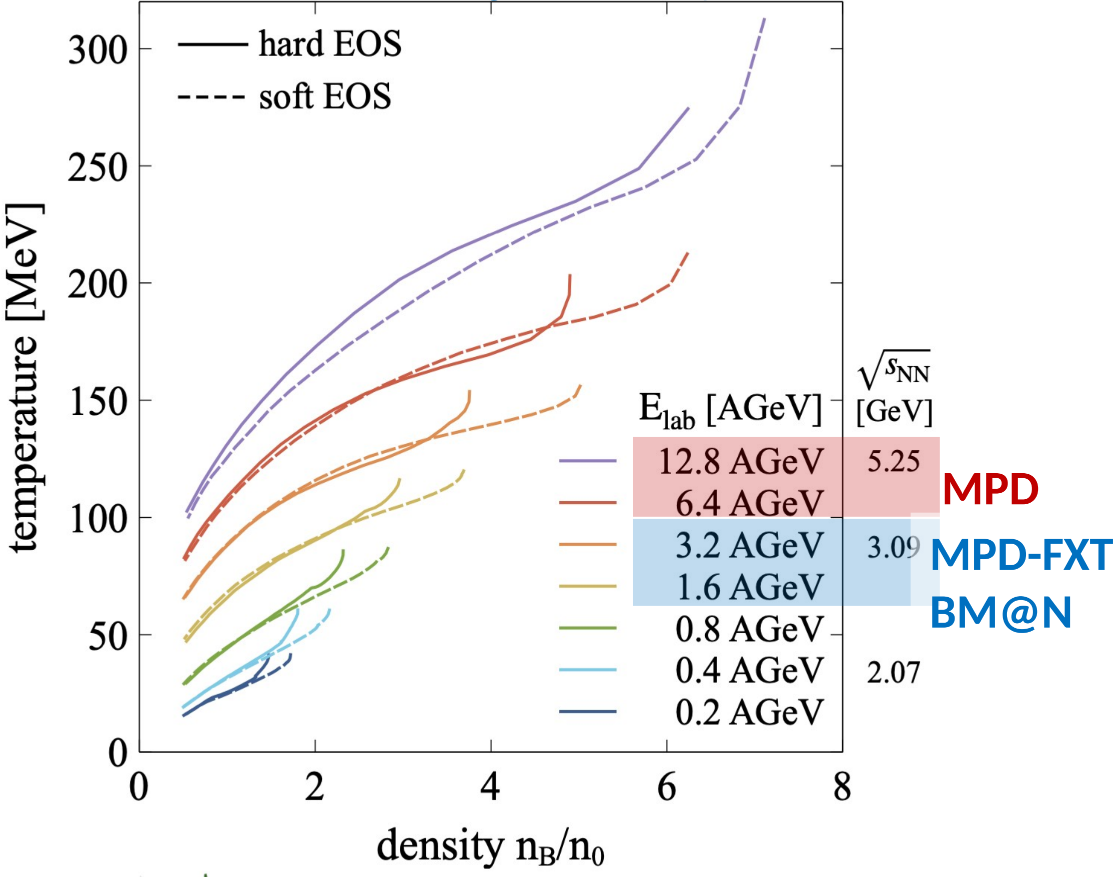
W. Lin, C. M. Ko, B.A. Li, B. Zhang and S. Pal:
sical Review C 72, 064901 (2005).

Sensitivity of the collective flow to the EOS

A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080



A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080



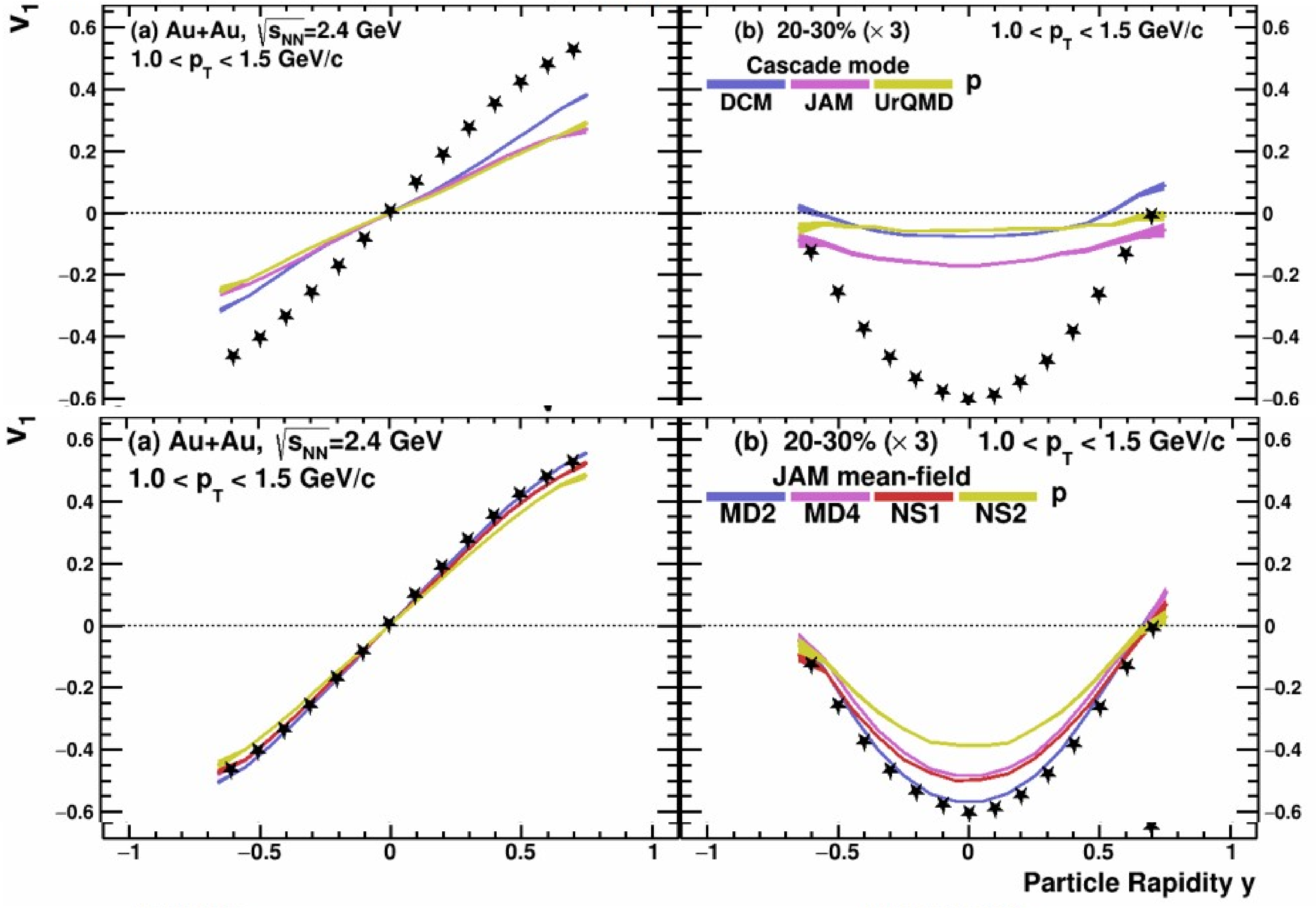
Incompressibility K_0:
parameter which specifies the behavior of EOS in the given baryon densities $K_0 = K_0(n_B)$

Models with flexible EOS for different (K_0, n_B) are required

Nuclotron-NICA coverage in terms of density: $2 \lesssim n_B/n_0 \lesssim 8$

Selecting the model

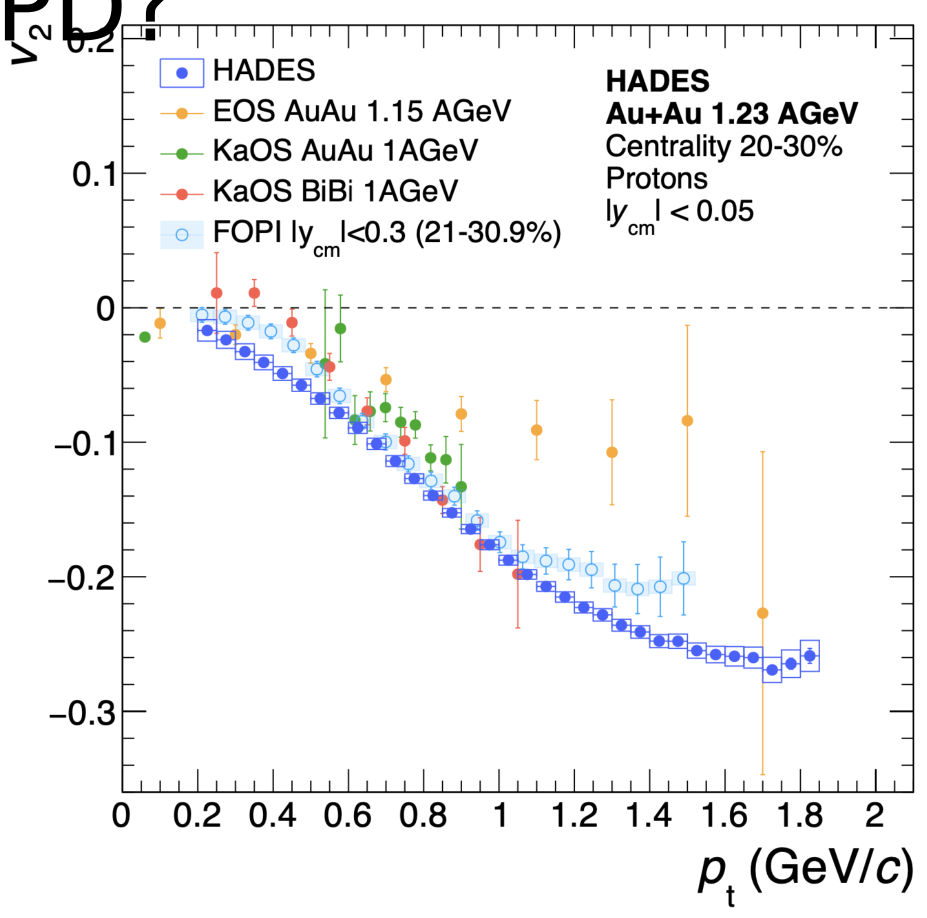
P.Parfenov Particles 5 (2022) 4, 561-579

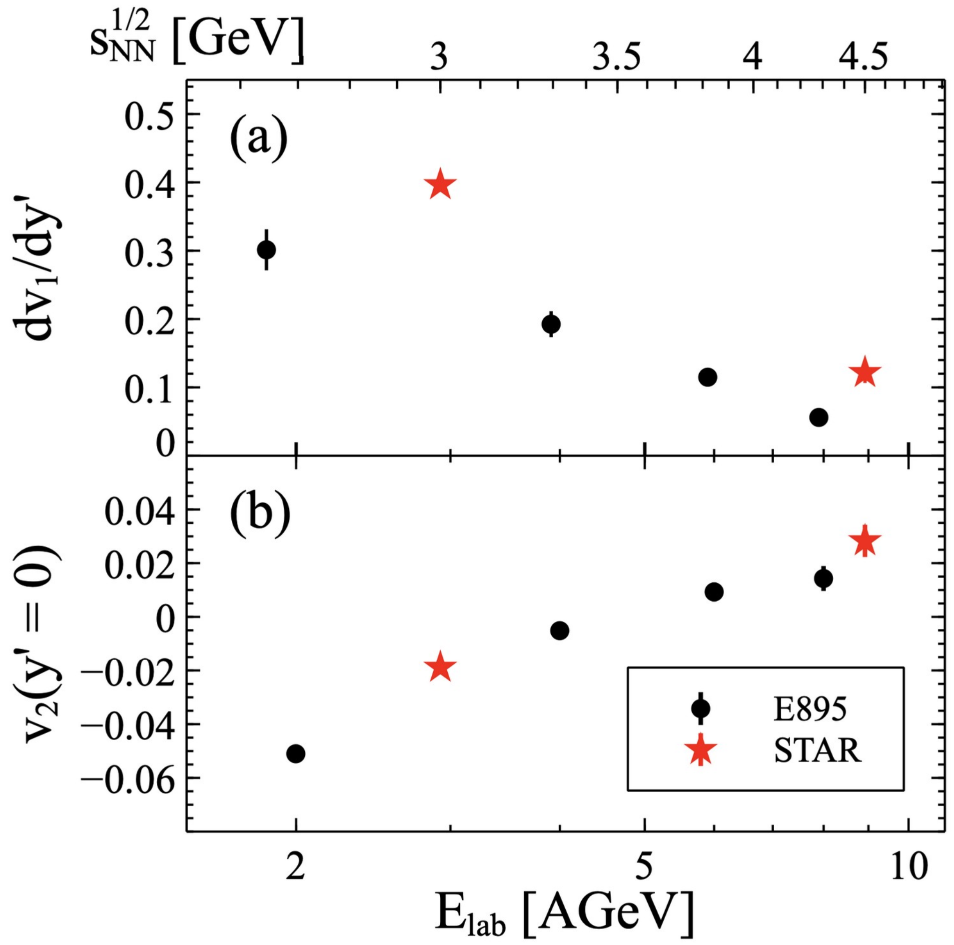


Cascade models fail to reproduce v_n at low-energy heavy-ion collision

Mean field models reproduce the v_n rather well

Why do we need new measurements at BM@N and MPD?



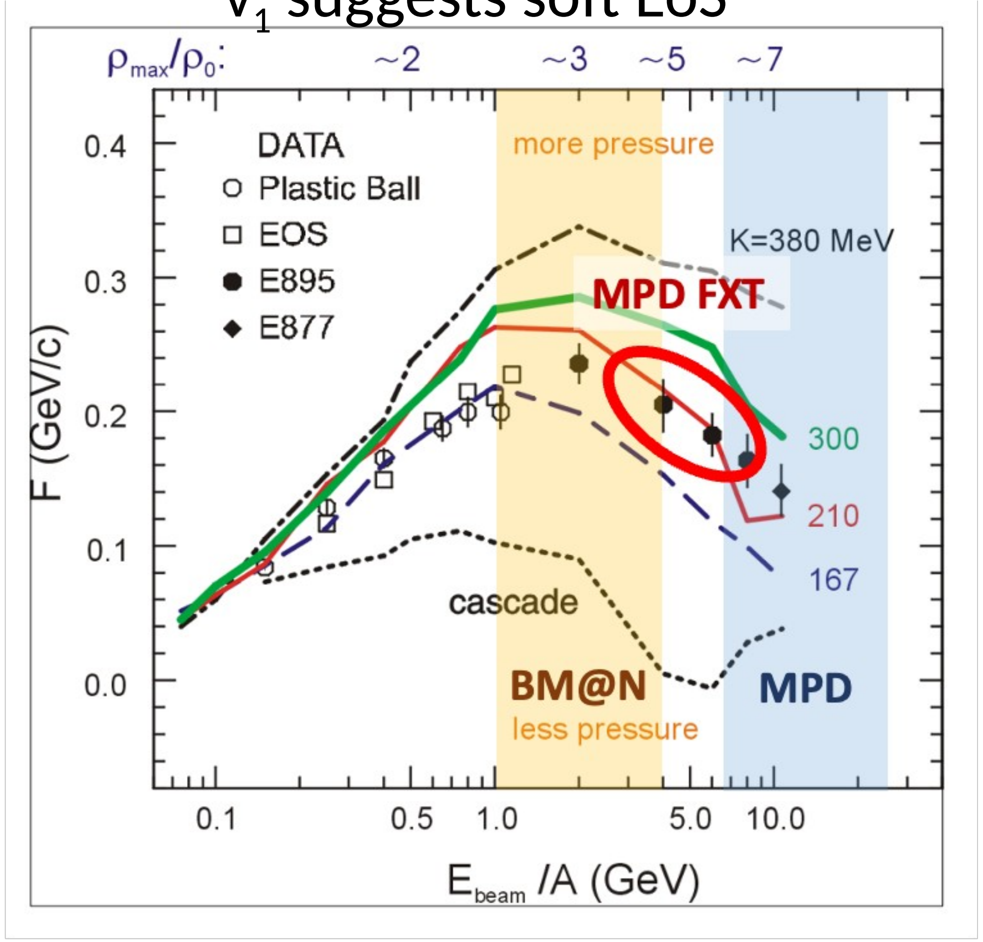


- The main source of existing systematic errors in v_n measurements is the difference between results from different experiments (for example, FOPI and HADES, E895 and STAR)
- New data from the future BM@N ($\sqrt{s_{NN}}$=2.3-3.3 GeV) and MPD ($\sqrt{s_{NN}}$=4-11 GeV) experiments will provide more detailed and robust v_n measurements

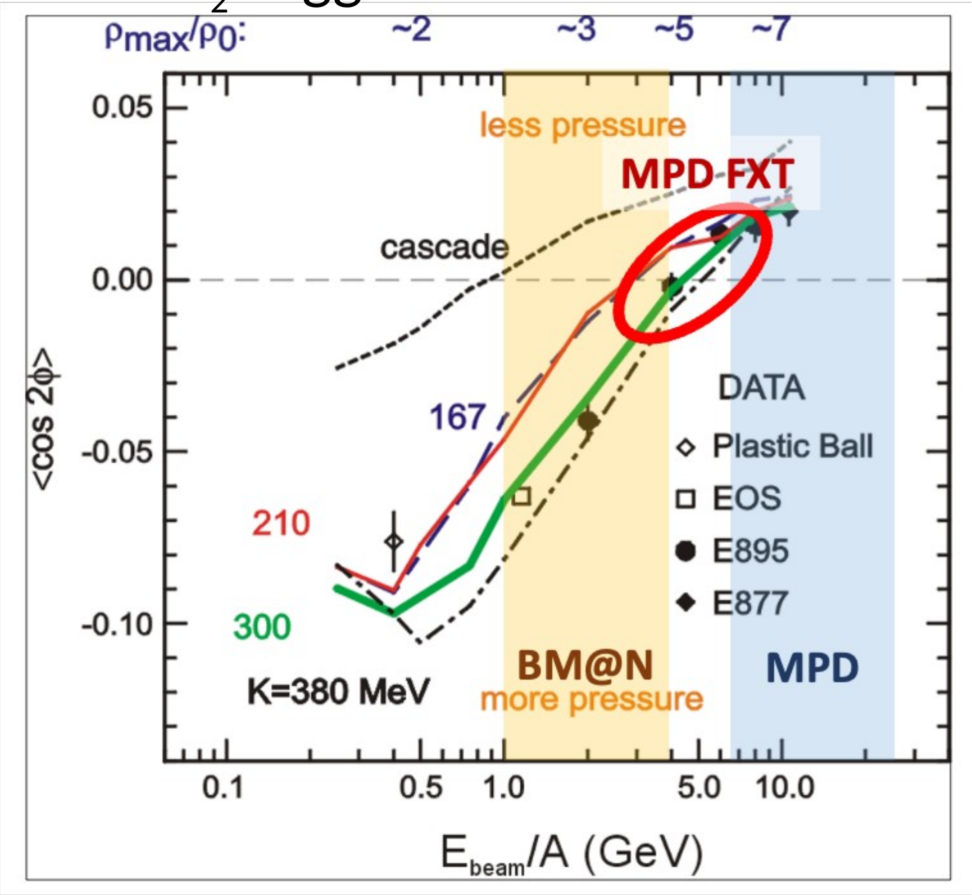
v_n at Nuclotron-NICA energies

P. DANIELEWICZ, R. LACEY, W. LYNCH
10.1126/science.1078070

v_1 suggests soft EoS

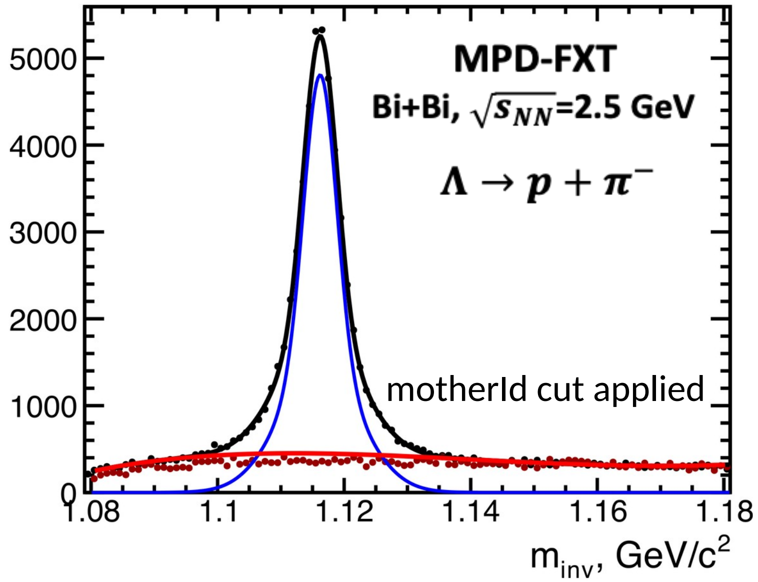


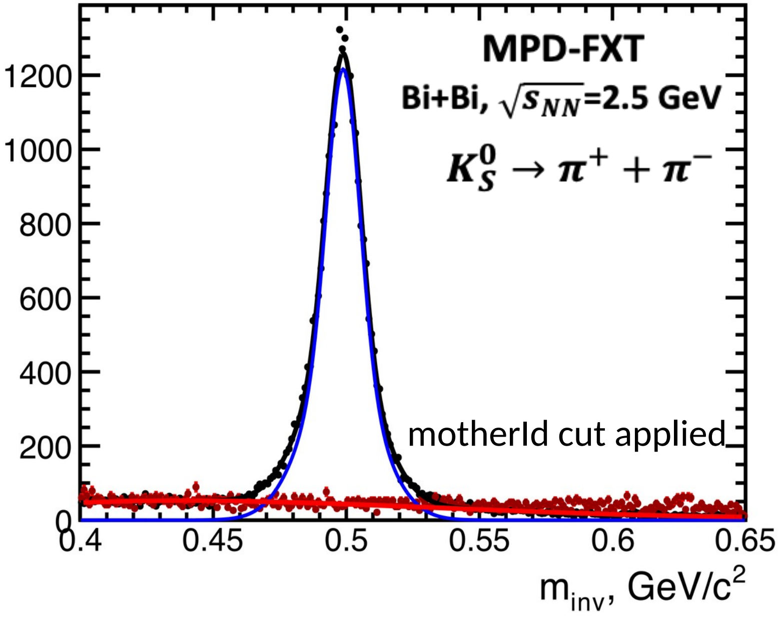
v_2 suggests hard EoS



- **v_n results from the E895 experiment are ambiguous:**
  - v_1 suggests EoS and v_2 suggests hard EoS
- **Additional experimental data are required to address this discrepancy**

V0 selection: PFSimple





PFSimple: interface for the KFParticle package

KFParticle: package developed for complete reconstruction of short-lived particles

- Successfully used in many experiments
- Based on the Kalman filter mathematics
- Independent in the sense of experimental setup (collider, fixed target)

First tests for Λ, K_S^0 from the MPD-FXT production are ready:

- Basic topological cuts:

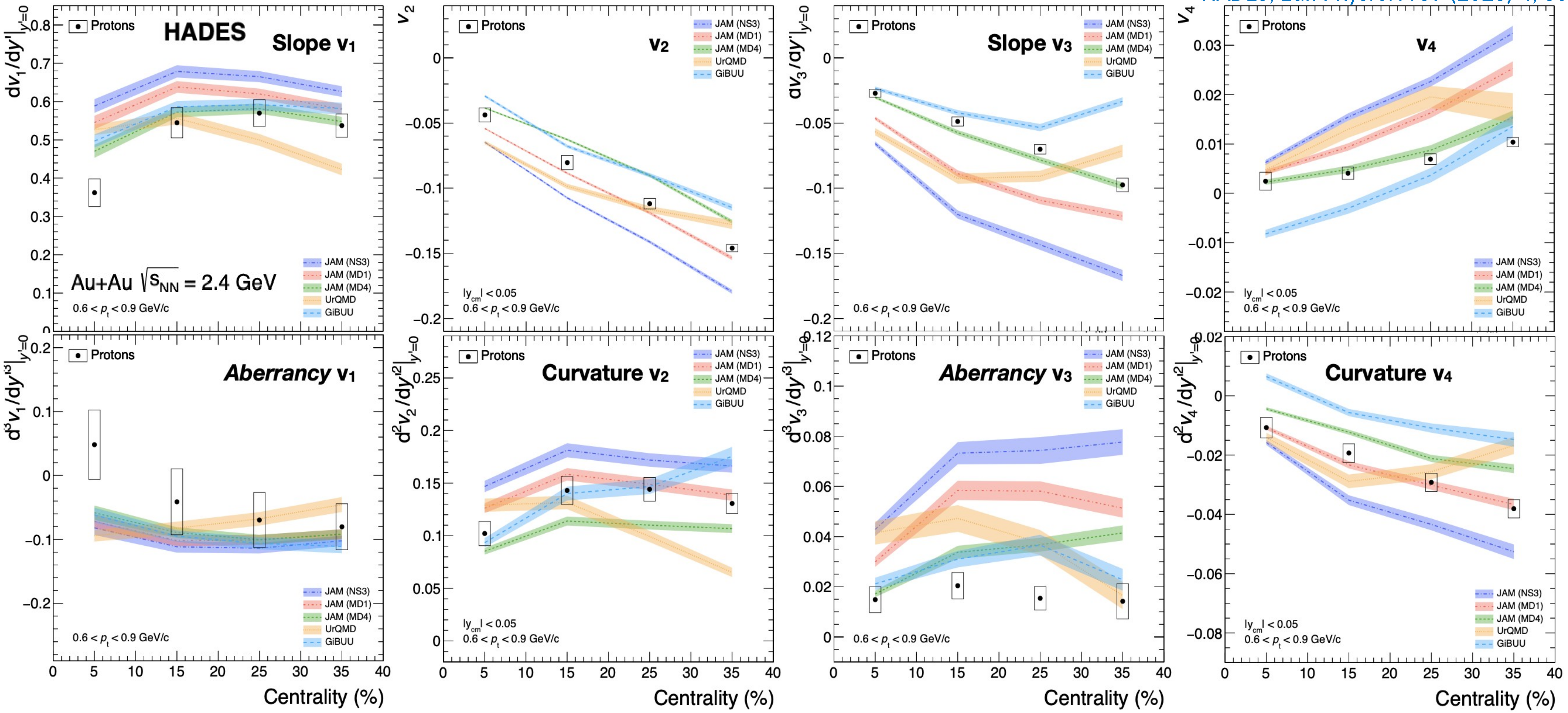
$$\chi^2_{topo} < 50, \chi^2_{geo} < 50, L > 3\ cm, \frac{L}{dL} > 5\ cm$$

- Signal extraction: sideband fits, rotation background were tested

PFSimple is already available as a module in the cvmfs

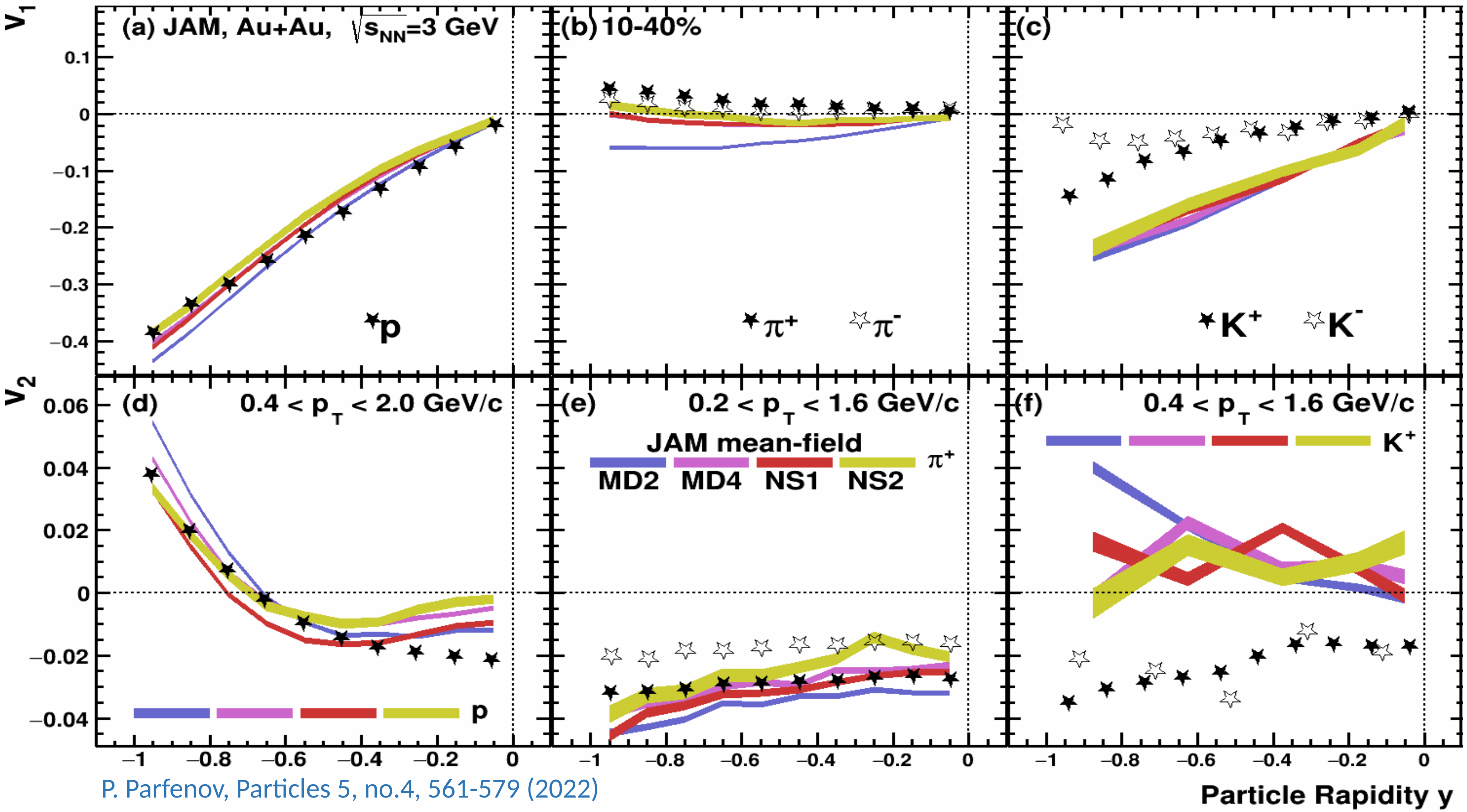
$v_n(y)$ in Au+Au $\sqrt{s_{NN}}$=2.4 GeV: models vs. HADES data

HADES, Eur. Phys. J. A 59 (2023) 4, 80



Overall trend reasonably well described, but no model works everywhere

$v_{1,2}(y)$ in Au+Au $\sqrt{s_{NN}}$=3 GeV: model vs. STAR data



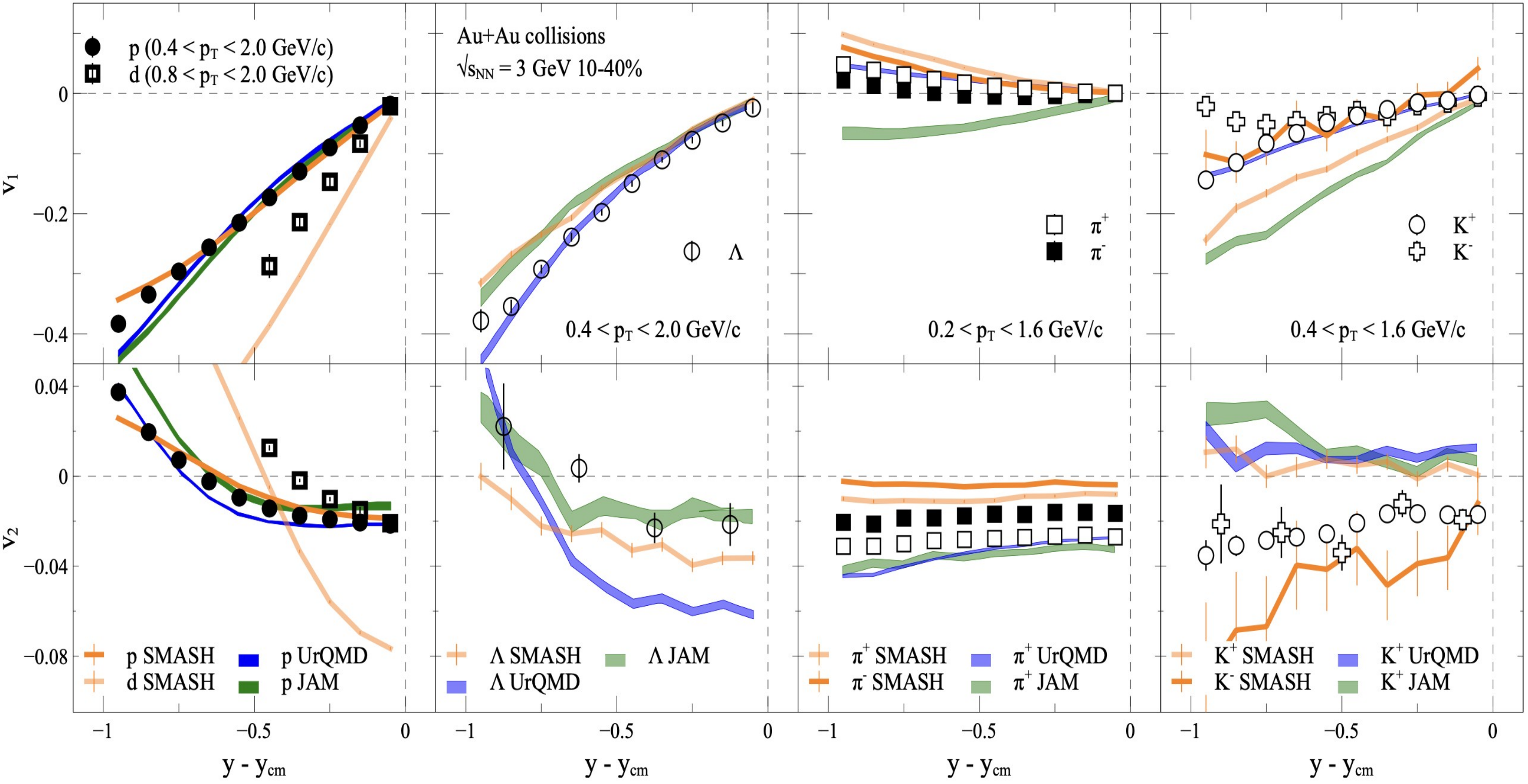
P. Parfenov, Particles 5, no.4, 561-579 (2022)

Models do not describe all particle species equally well

v_1, v_2 of protons are described by JAM, UrQMD (hard EOS) and SMASH (hard EOS with softening at higher densities)

$v_{1,2}(y)$ in Au+Au $\sqrt{s_{NN}}$=3 GeV: model vs. STAR data

A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080



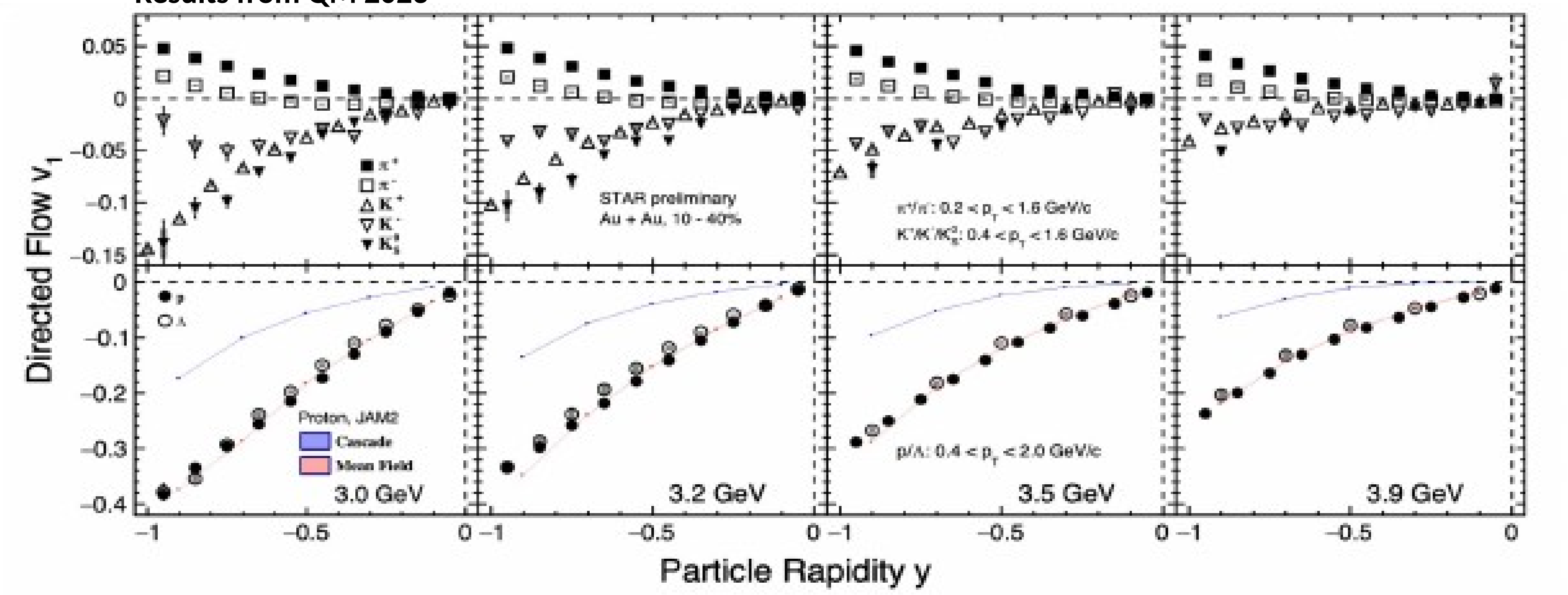
Model description of v_n:

- Good overall agreement for v_n of protons
- v_n of light nuclei is not described
- v_n of Λ is not well described
  - nucleon-hyperon and hyperon-hyperon interactions
- Light mesons (π,K) are not described
  - No mean-field for mesons

Models have a huge room for improvement in terms of describing v_n

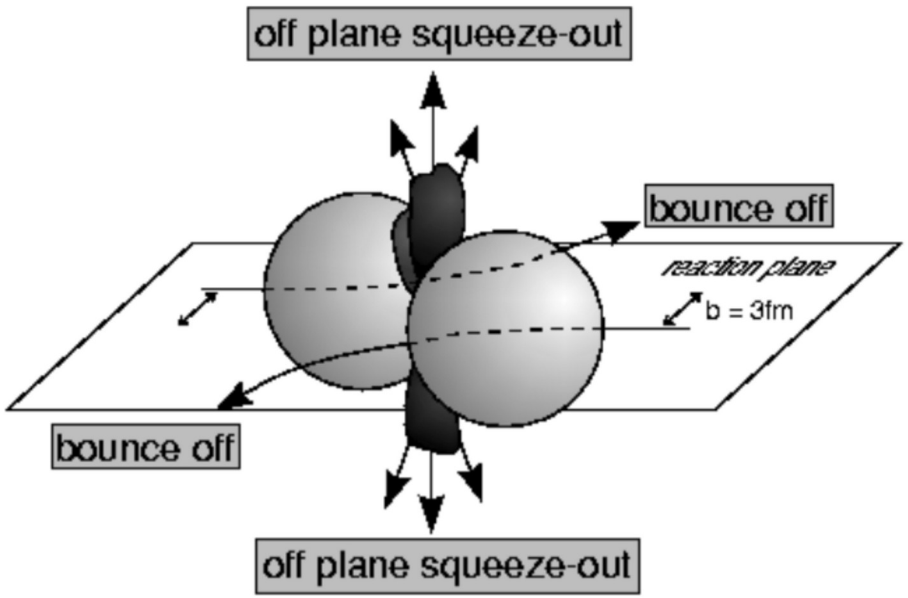
New STAR results from BES-II

Results from QM 2023



- New preliminary results from STAR BES-II were presented at QM-2023 for Au+Au at $\sqrt{s_{NN}}$=3, 3.2, 3.5, 3.9 GeV

Anisotropic flow & spectators



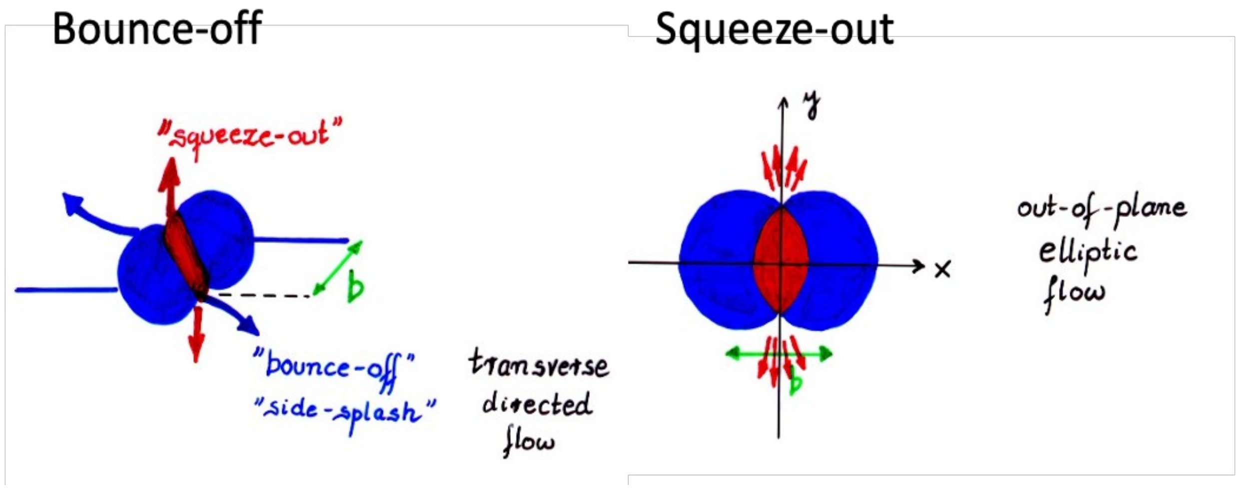
The azimuthal angle distribution is decomposed in a Fourier series relative to reaction plane angle:

$$\rho(\varphi - \Psi_{RP}) = \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_{RP})\right)$$

Anisotropic flow:

$$v_n = \langle \cos\left[n(\varphi - \Psi_{RP})\right]\rangle$$

v_1 - directed flow, v_2 - elliptic flow

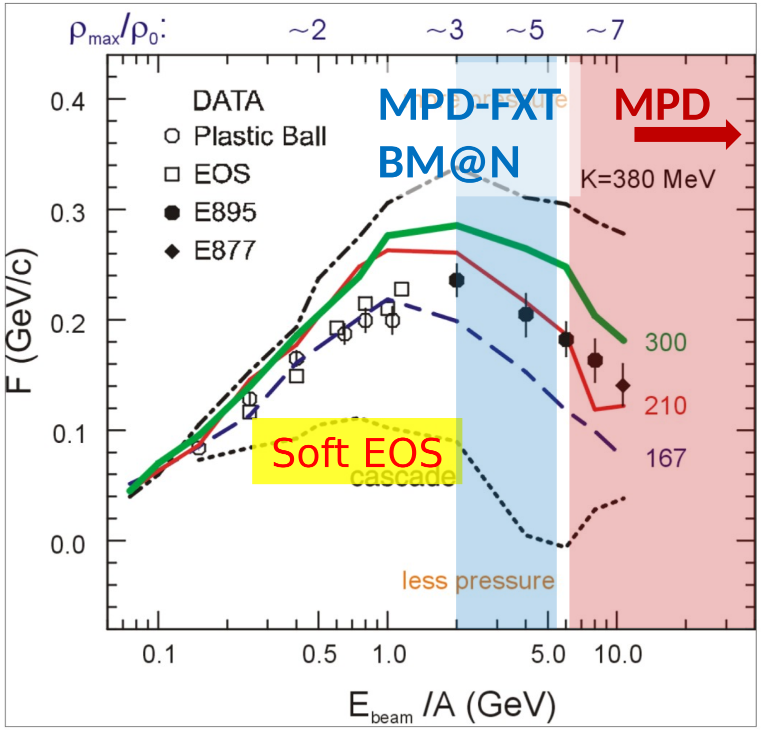


Anisotropic flow is sensitive to:

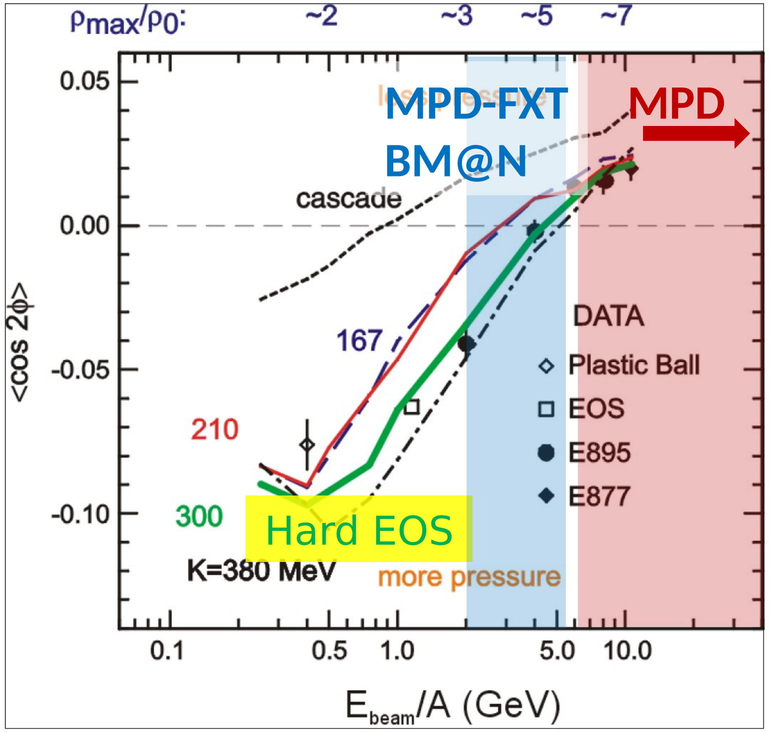
- Compressibility of the created matter $\left(t_{exp} = R/c_s,\ c_s = c\sqrt{dp/d\varepsilon}\right)$
- Time of the interaction between overlap region and spectators $\left(t_{pass} = 2R/\gamma_{CM}\beta_{CM}\right)$

Sensitivity of the collective flow to the EOS

P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592



$$F = \left. \frac{d\langle p_x/A \rangle}{d(y/y_{cm})} \right|_{y/y_{cm}=1}$$



$$v_2 \equiv \langle \cos(2(\varphi - \Psi_{RP})) \rangle$$

EoS extraction: define incompressibility

$$K_0 = 9\rho^2 \frac{\partial^2 (E_A)}{\partial \rho^2}$$

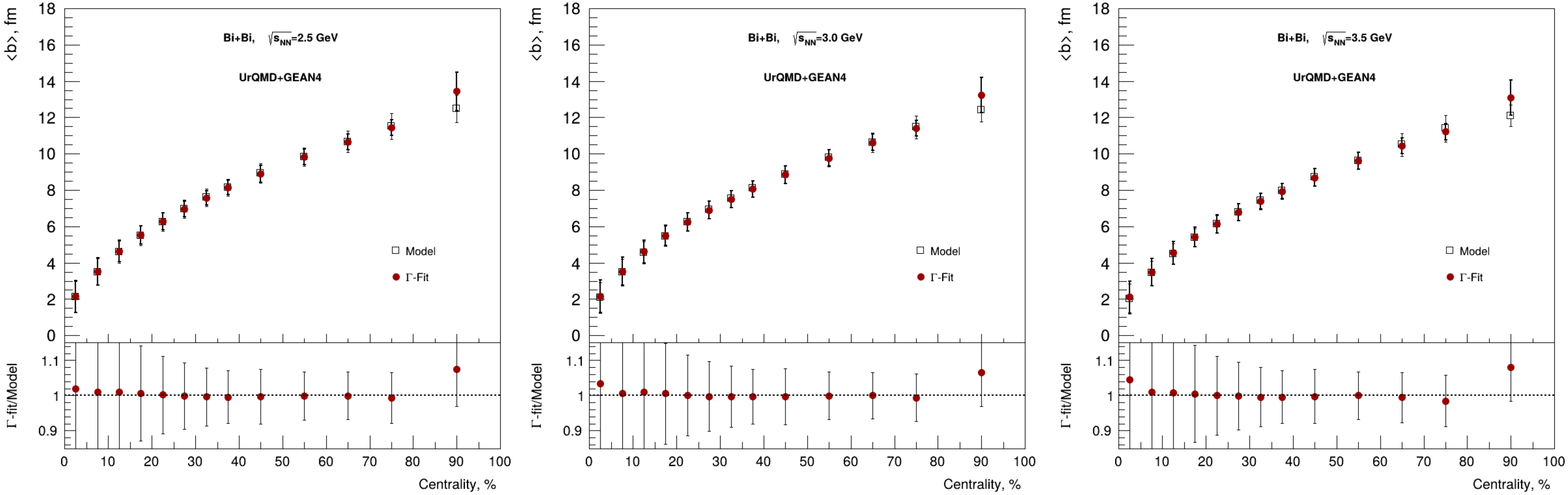
Discrepancy in the interpretation:

- v_1 suggests soft EoS (K_0≈210 MeV)
- v_2 suggests hard EoS (K_0≈380 MeV)

New measurements using new data and modern analysis techniques might address this discrepancy

Additional measurements are essential to clarify the previous results

Centrality determination: <b> vs Centrality



Cuts on tracks:

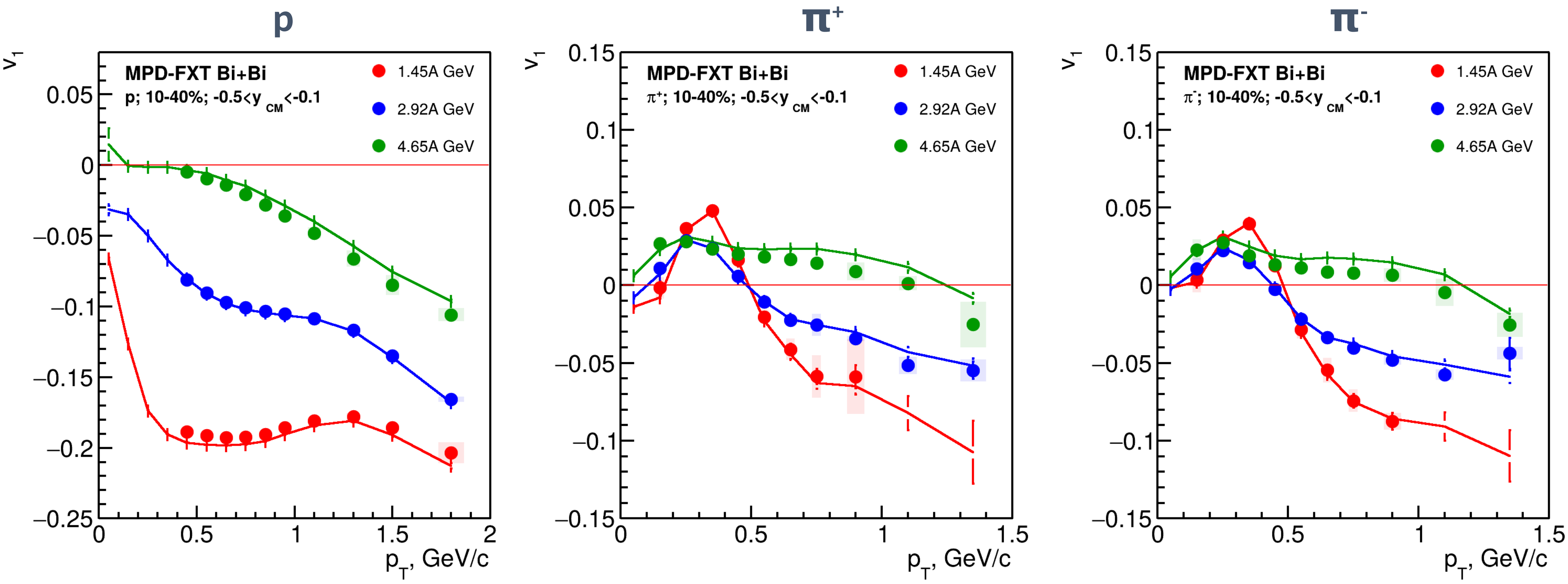
- Nhits>16
- $0 < \eta < 2$

Good agreement between fit and data

Multiplicity-based centrality determination using inverse Bayes was used

Results: $v_1(p_T)$

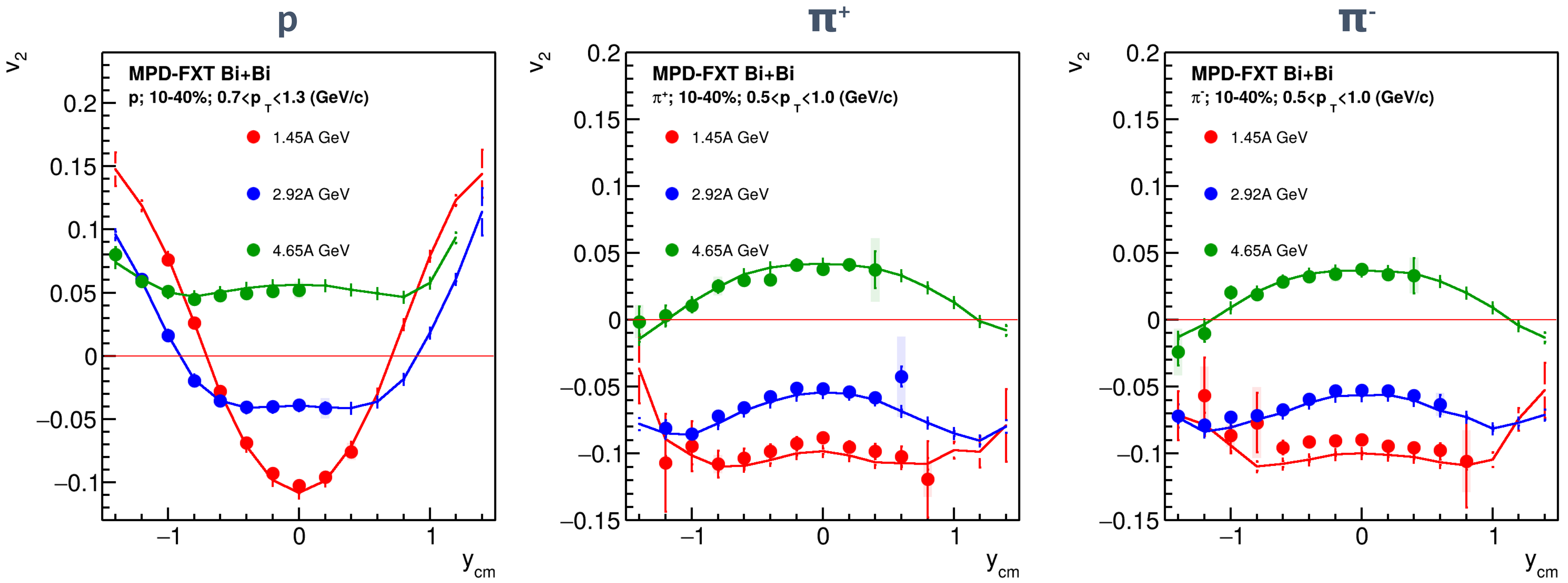
Systematics: xx, yy, F1, F2, F3



Good agreement with MC data

Results: $v_2(y)$

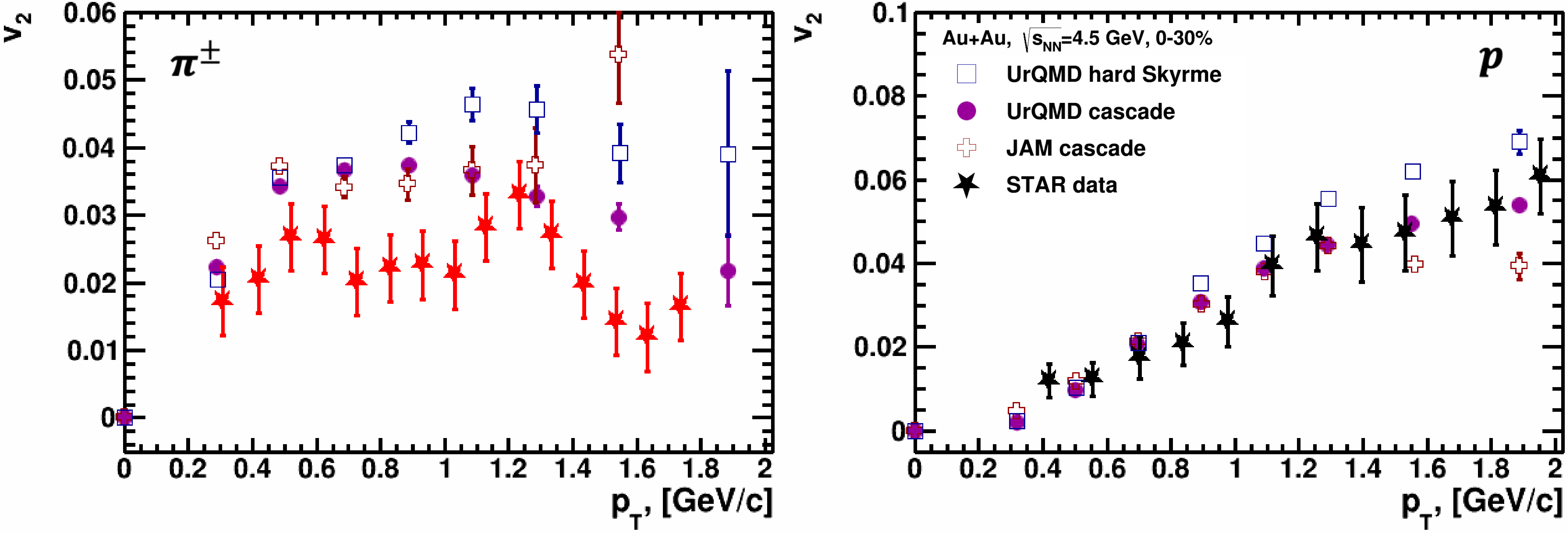
Systematics: xxx, xyy



Good agreement with MC data

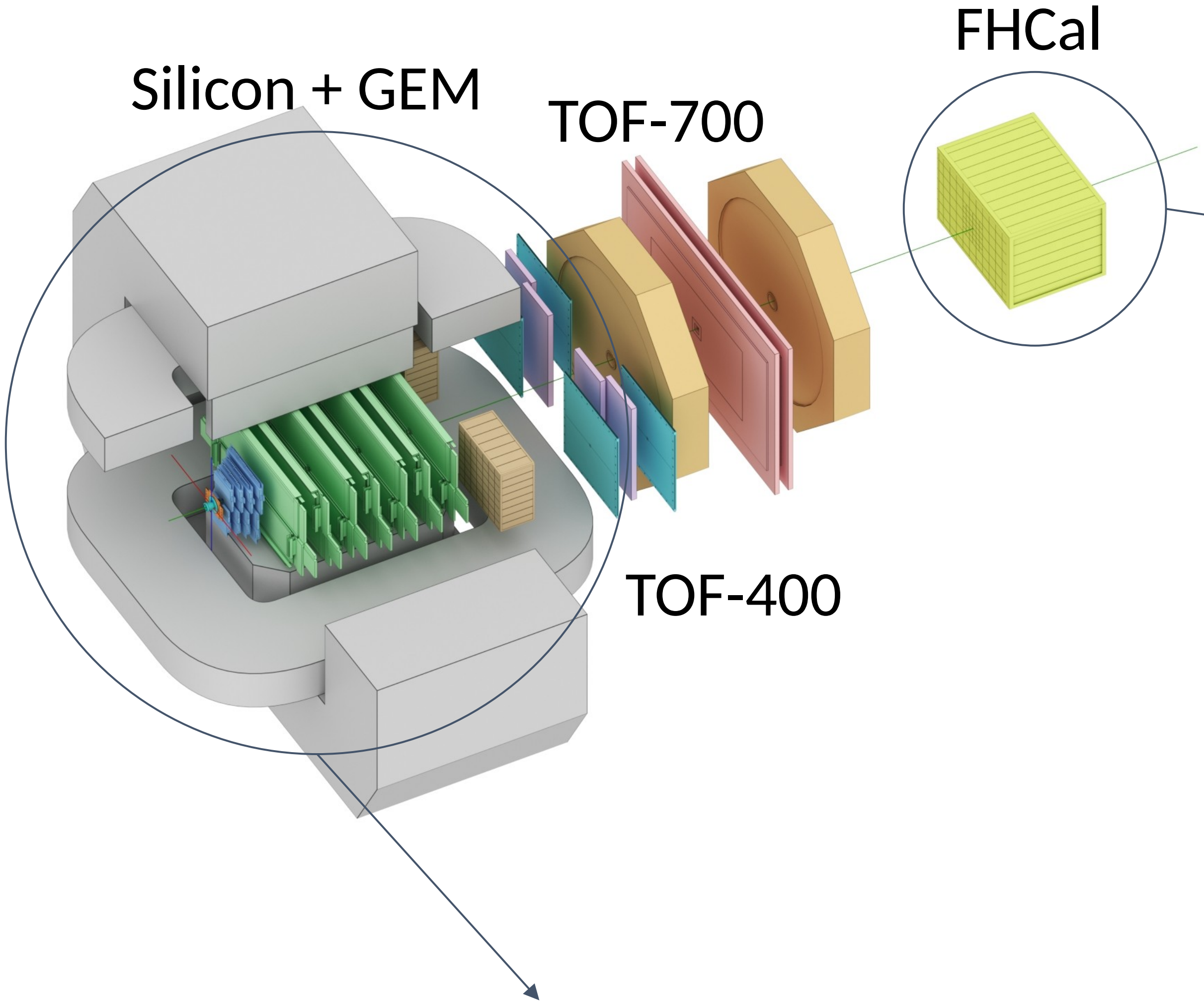
Elliptic flow at NICA energies: Models vs. Data comparison

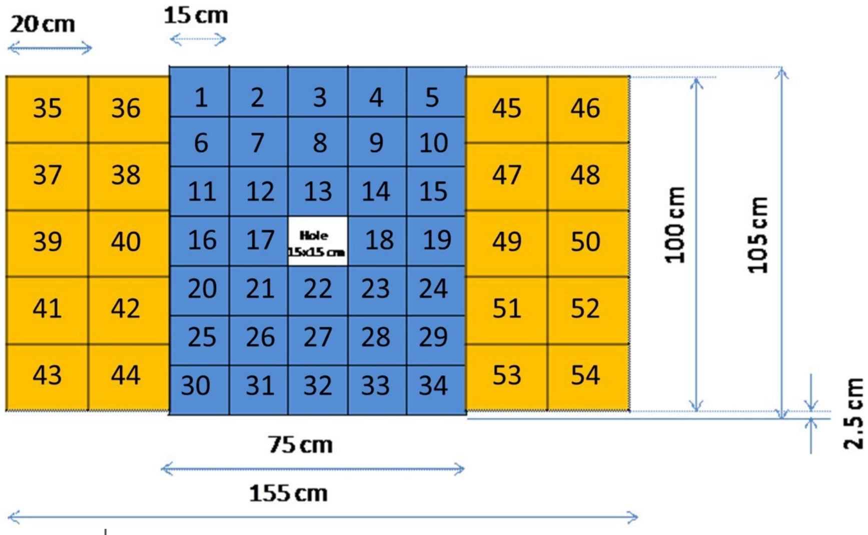
Experimental data is taken from: *Phys.Rev.C* 103 (2021) 3, 034908

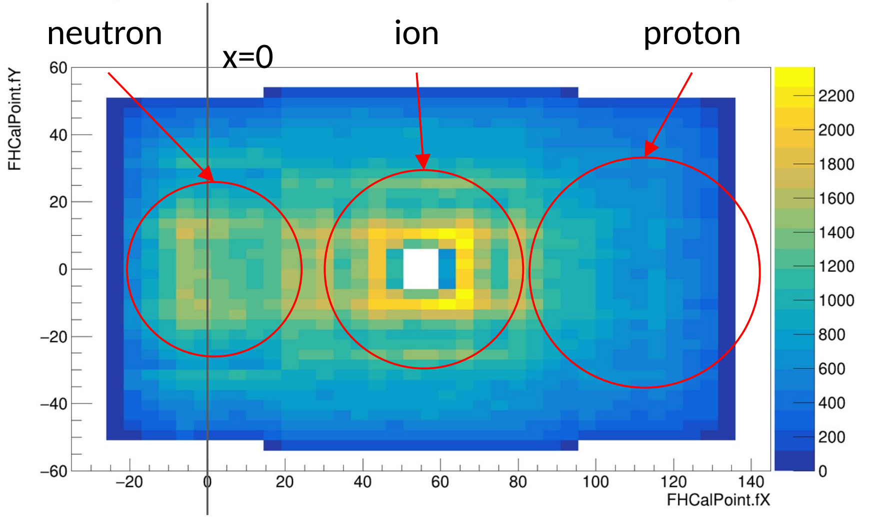


Pure String/Hadronic Cascade models give similar v_2 signal compared to STAR data for Au+Au $\sqrt{s_{NN}}$ =4.5 GeV

The BM@N experiment (GEANT4 simulation for RUN8)



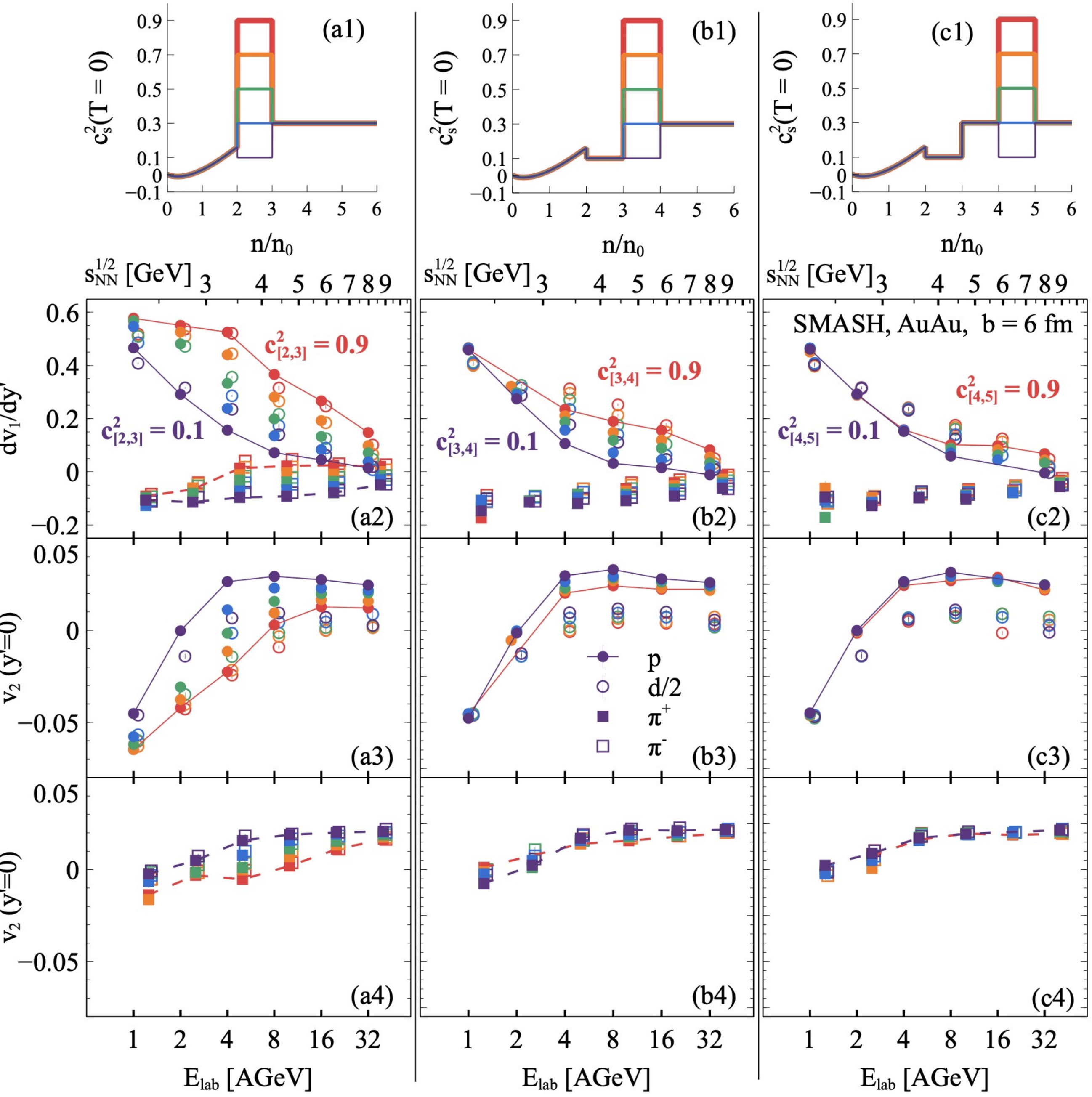




Square-like tracking system within the magnetic field deflecting particles along X-axis

Charge splitting on the surface of the FHCal is observed due to magnetic field

Sensitivity of the collective flow to the EOS



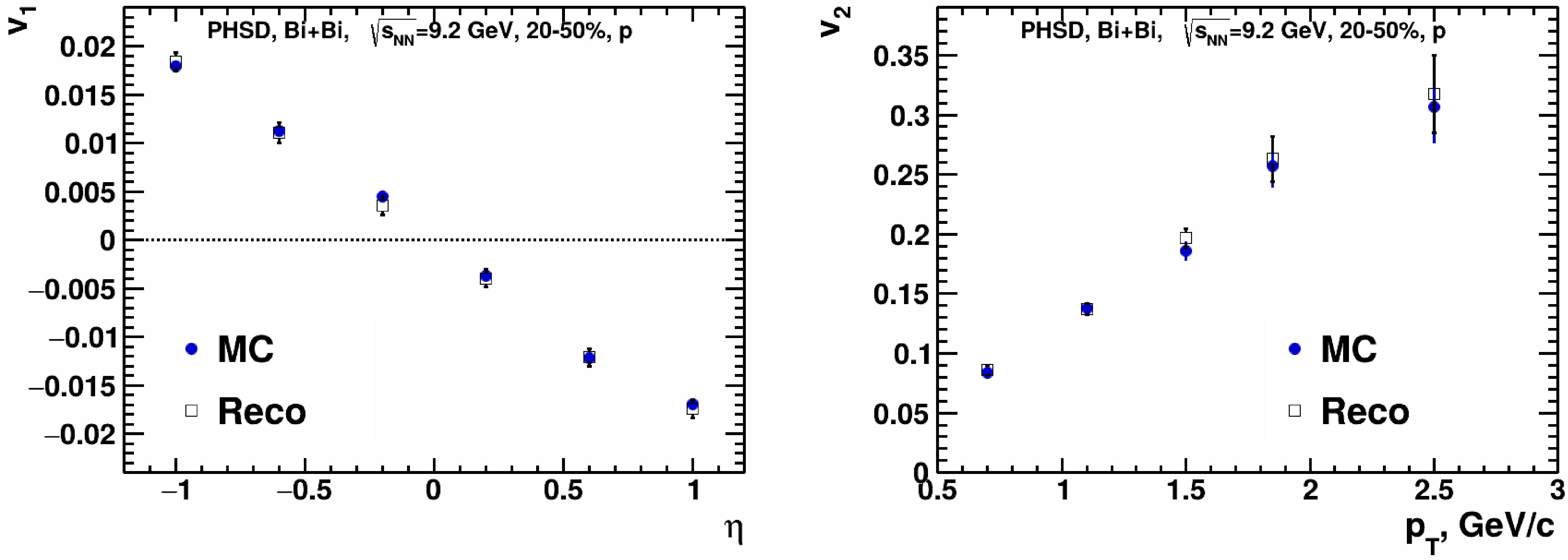
A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080

- SMASH model with flexible EOS was used to test the sensitivity of the v_n to changes of EOS in a specific density range n/n_0:
  - $\mathbf{2 < n_B/n_0 < 3}$: dv_1/dy' and v_2 of pions, protons and deuterons are very sensitive to the EOS
  - $\mathbf{3 < n_B/n_0 < 4}$: dv_1/dy' and v_2 of protons and deuterons are sensitive to the EOS
  - $\mathbf{4 < n_B/n_0 < 5}$: weak sensitivity to the EOS

The most precise constraints can be achieved from the flow of identified hadrons (*π±,K±,p,…*) and light nuclei (*d,t,…*)

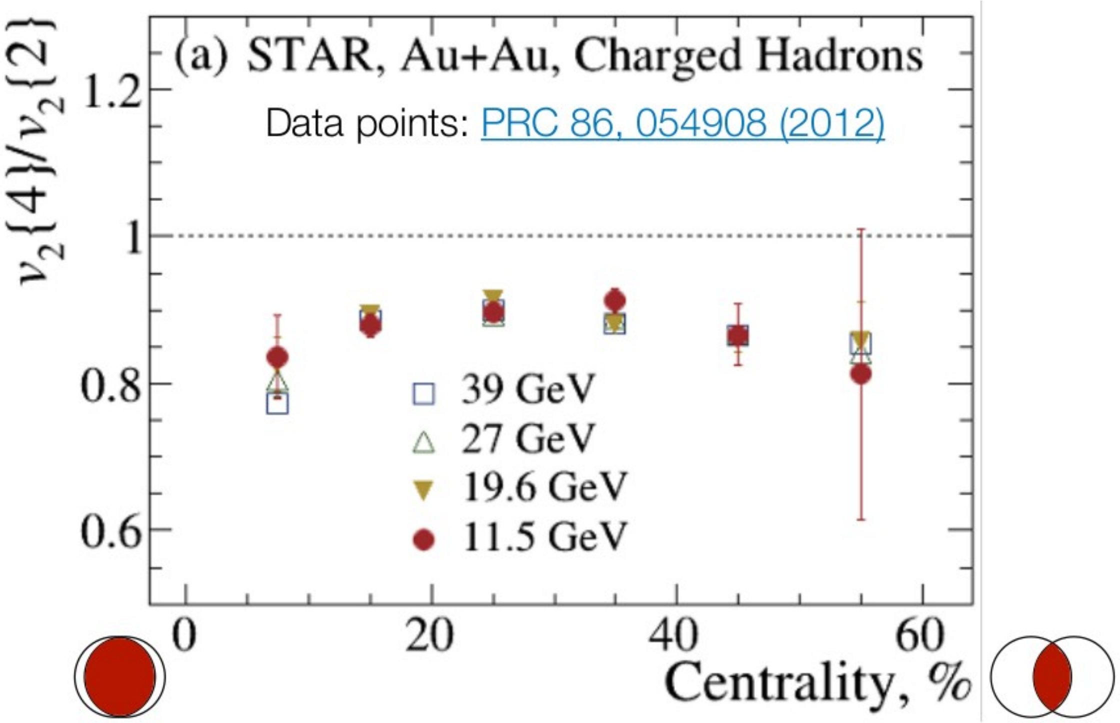
Performance of $v_{1,2}$ of Λ hyperons in MPD

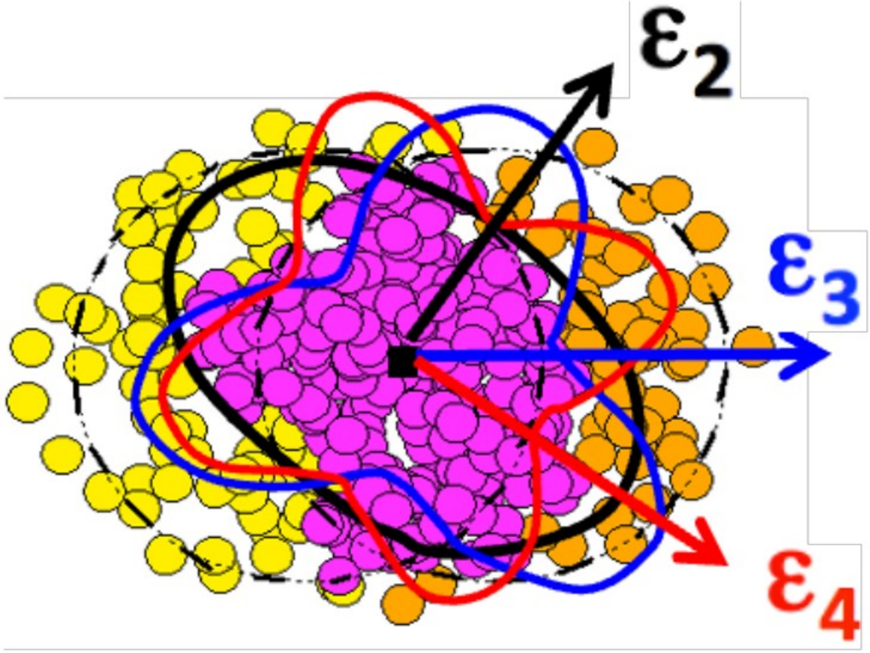
V. Troshin



Good performance for v_1, v_2 using invariant mass fit and event plane methods

Motivation of elliptic flow fluctuation study



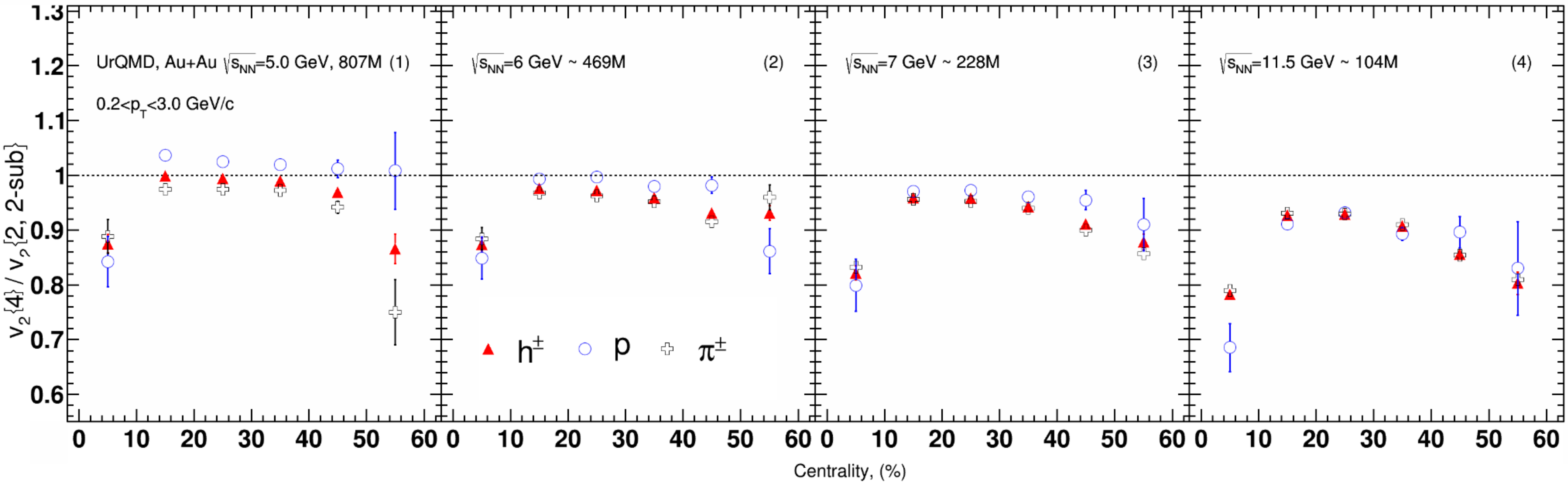


- Indicate a dominated initial state driven uctuations $\sigma_{\varepsilon 2}$
- Provide constraints for IS models and shear viscosity η(T/s)

How about v2 fluctuations at NICA energies?

Relative v_2 fluctuations of identified hadrons

For more details see A.Demanov's talk on ISHEP-2023



- Weak dependence between $v_2\{4\}/v_2\{2\}$ of protons and pions at 11.5 GeV
- The difference between $v_2\{4\}/v_2\{2\}$ of protons and pions increases with decreasing energy

Anisotropic flow at Nuclotron-NICA energies

Flow at >7.7 GeV, flow at 4.5 GeV, flow at <3 GeV
Our works so far with the collider mode
FXT allows to widen the energy coverage of MPD