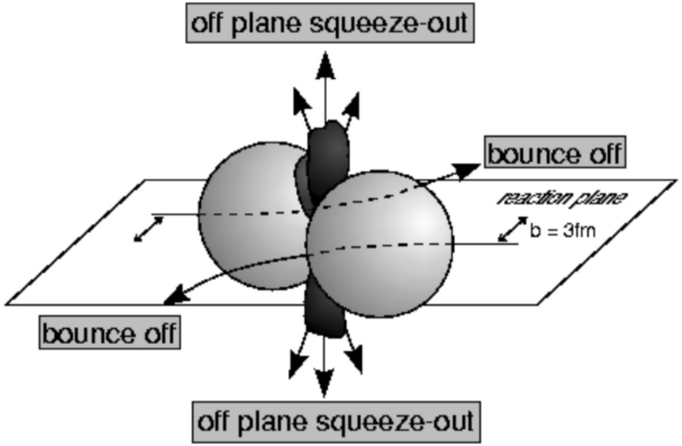
Update on the directed and elliptic flow measurements in Xe+W collisions at MPD-FXT

P. Parfenov, M. Mamaev and A. Taranenko
(NRNU MEPhI, JINR)

Anisotropic flow & spectators



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

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

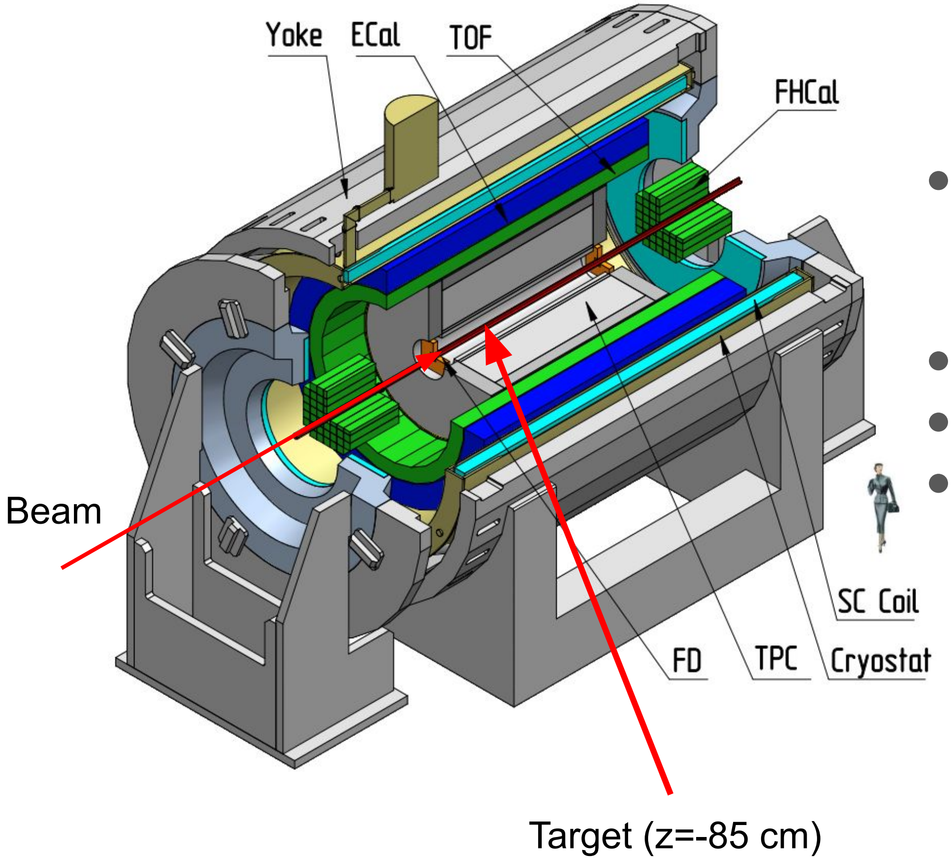
Anisotropic flow:

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

Anisotropic flow is sensitive to:

- Time of the interaction between overlap region and spectators
- Compressibility of the created matter

MPD in Fixed-Target Mode (FXT)



- Model used: UrQMD mean-field
  - Xe+Xe, E_{kin}=2.5 AGeV ($\sqrt{s_{NN}}$ =2.87 GeV)
  - Xe+W, E_{kin}=2.5 AGeV ($\sqrt{s_{NN}}$ =2.87 GeV)
- Point-like target
- GEANT4 transport
- Particle species selection via TPC and TOF

Flow vectors

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

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

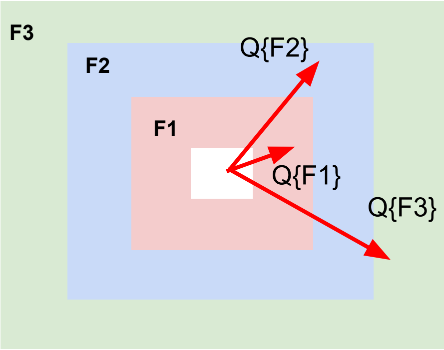
where φ is the azimuthal angle

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

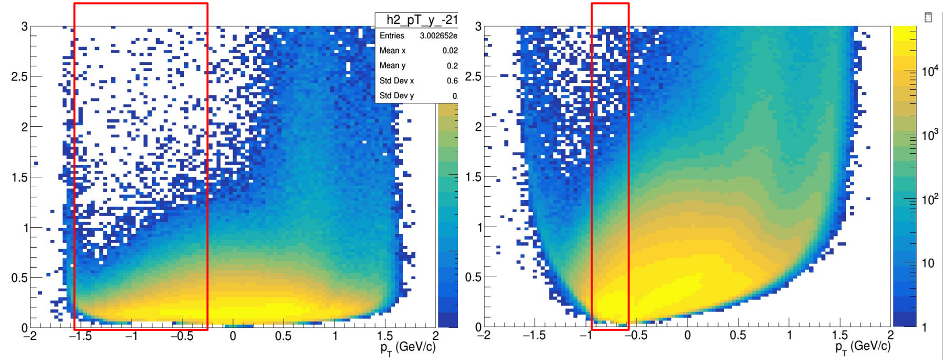
$$Q_n = \frac{\sum_{k=1}^{N} w_n^k u_n^k}{\sum_{k=1}^{N} w_n^k} = |Q_n| e^{in\Psi_n^{EP}}$$

Ψ_n^{EP} is the event plane angle

Modules of FHCal divided into 3 groups



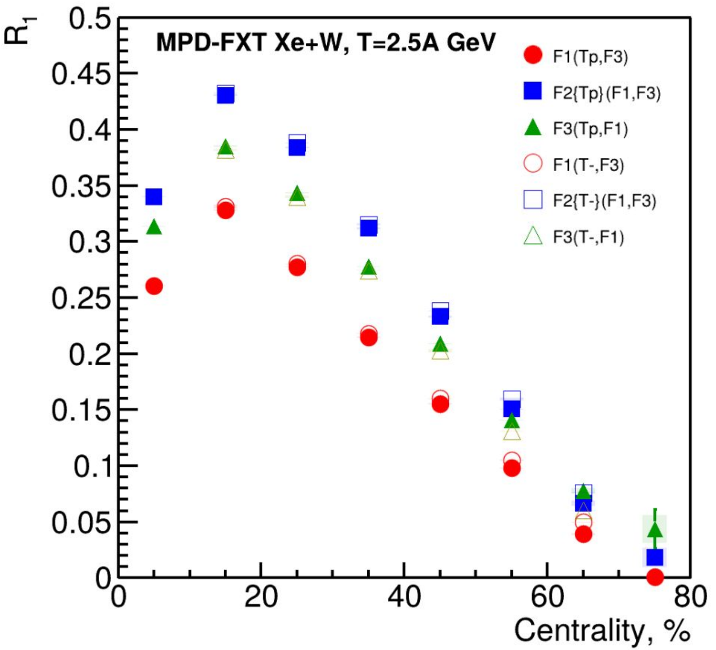
Tπ- Tp



Additional subevents from tracks not pointing at FHCal:
Tp: p; -1.0<y<-0.6;
Tπ: π-; -1.5<y<-0.2;

Flow methods for v_n calculation

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

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

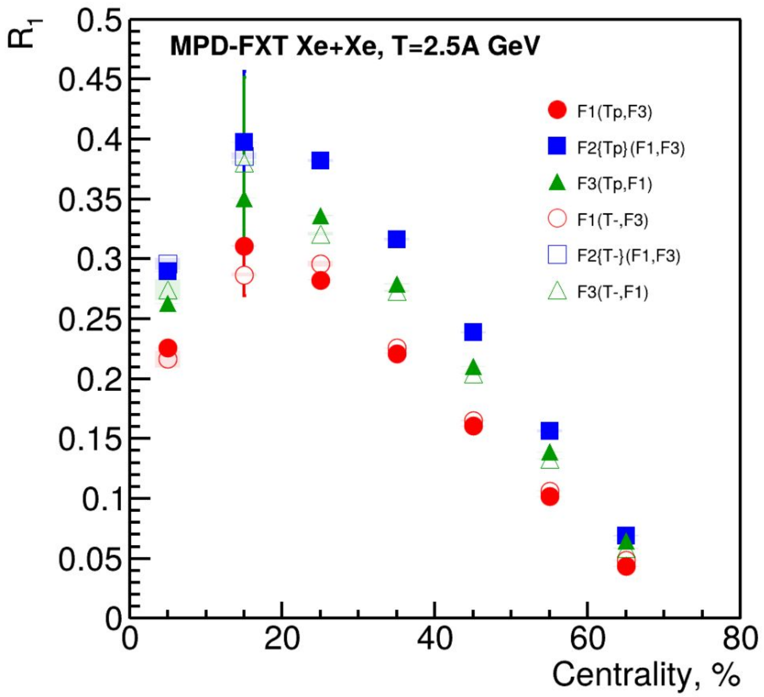
Symbol "F2(F1,F3)" means R_1 calculated via (3S resolution):

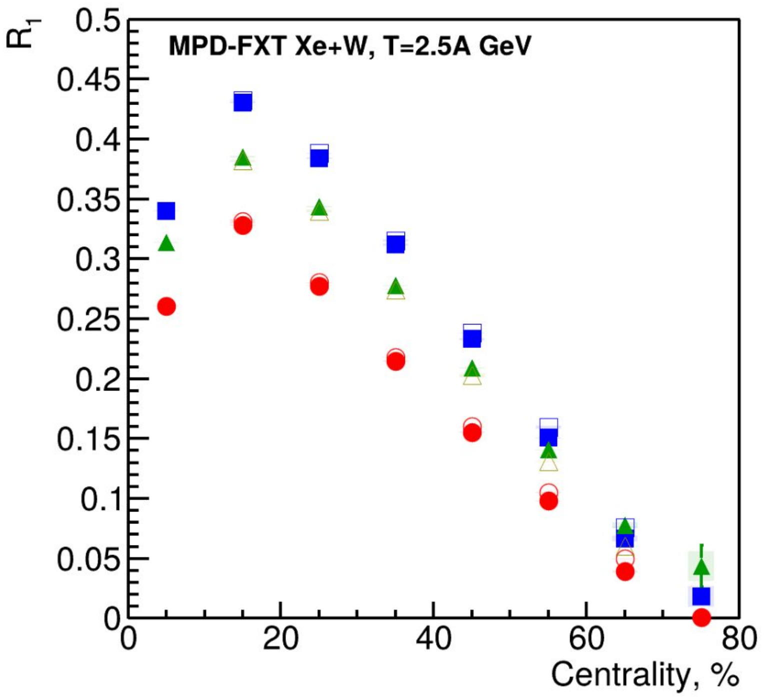
$$R_1^{F2(F1,F3)} = \frac{\sqrt{\langle Q_1^{F2} Q_1^{F1} \rangle \langle Q_1^{F2} Q_1^{F3} \rangle}}{\sqrt{\langle Q_1^{F1} Q_1^{F3} \rangle}}$$

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

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

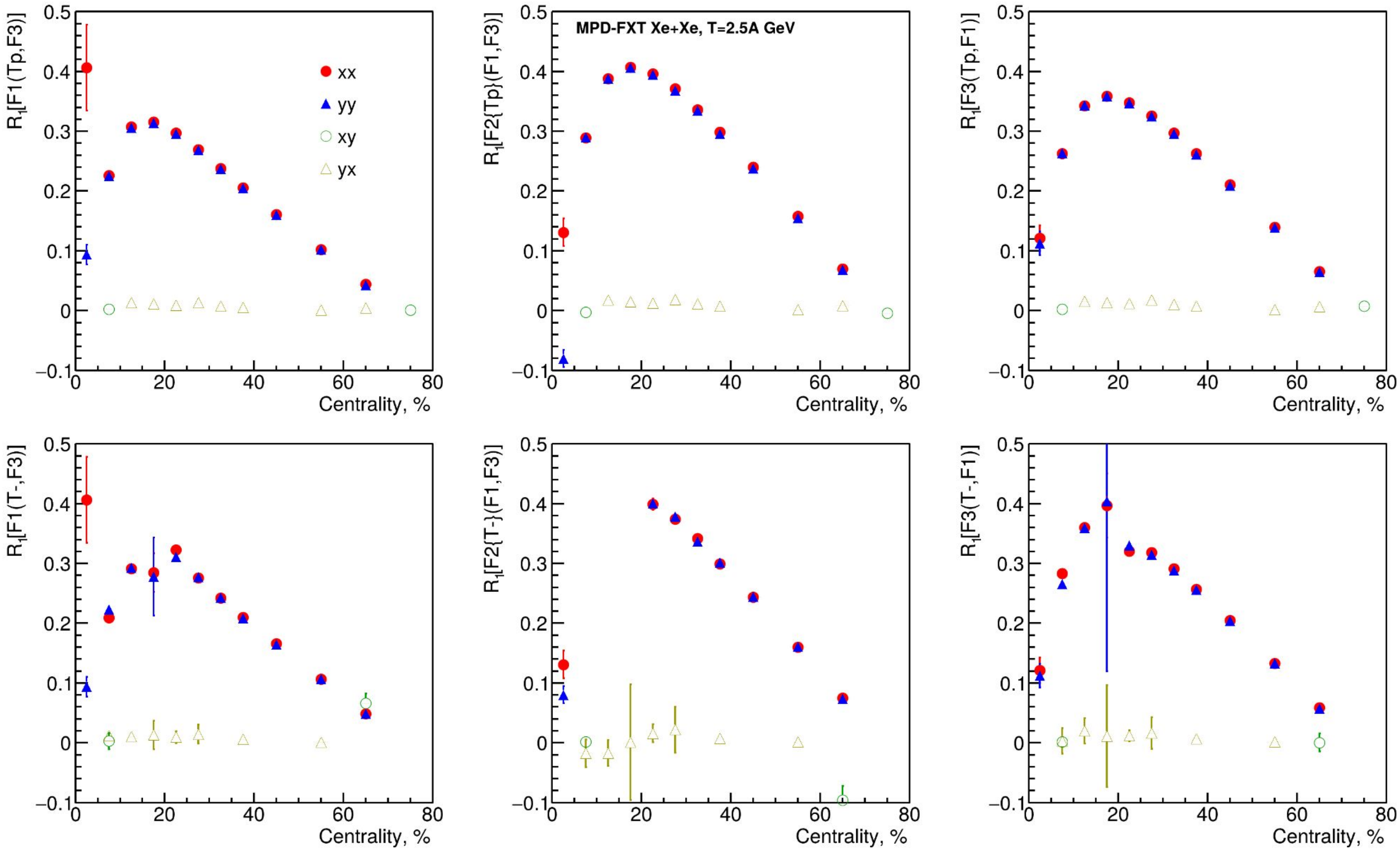
Results: resolution





Resolution using Tp and T- are in a good agreement for both Xe+Xe, Xe+W

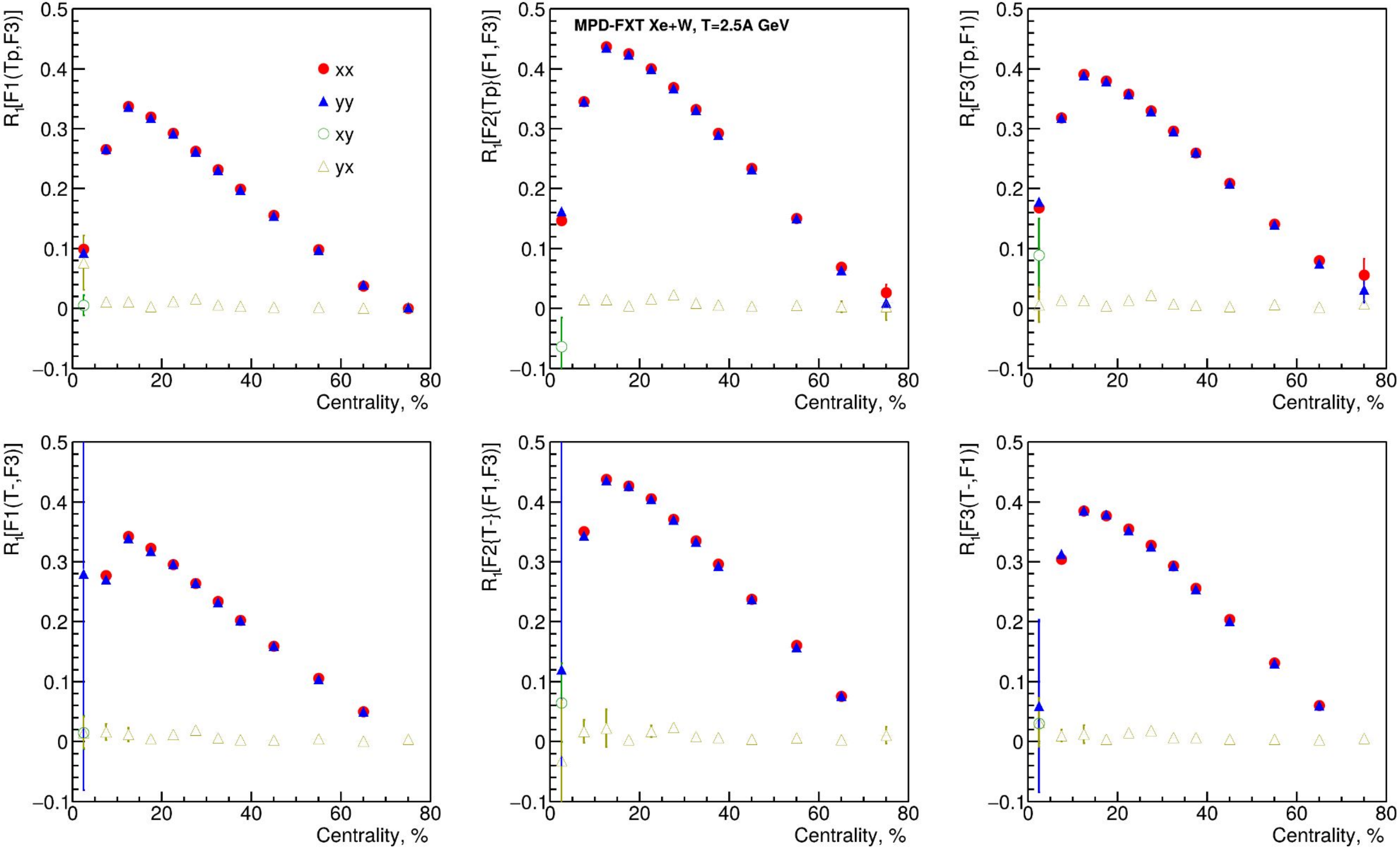
Resolution: components, Xe+Xe



xx=yy

xy=yx=0

Resolution: components, Xe+W

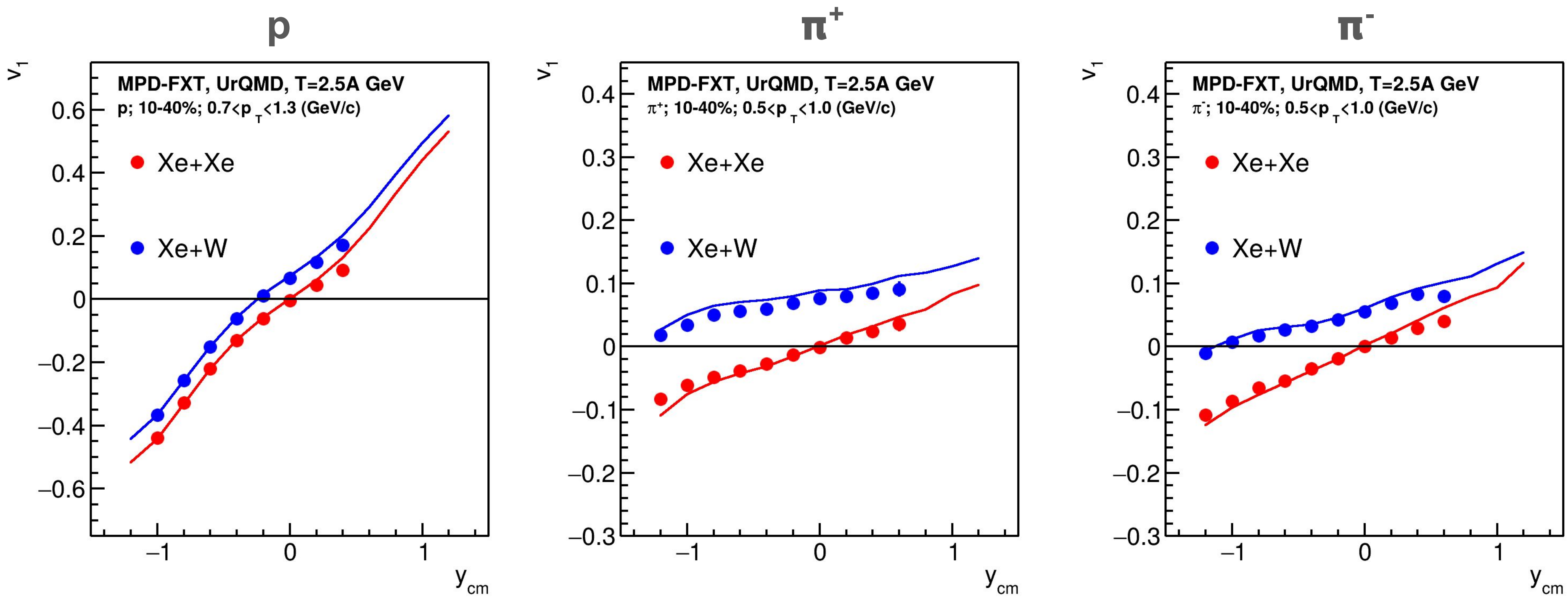


xx=yy

xy=yx=0

Results: $v_1(y)$

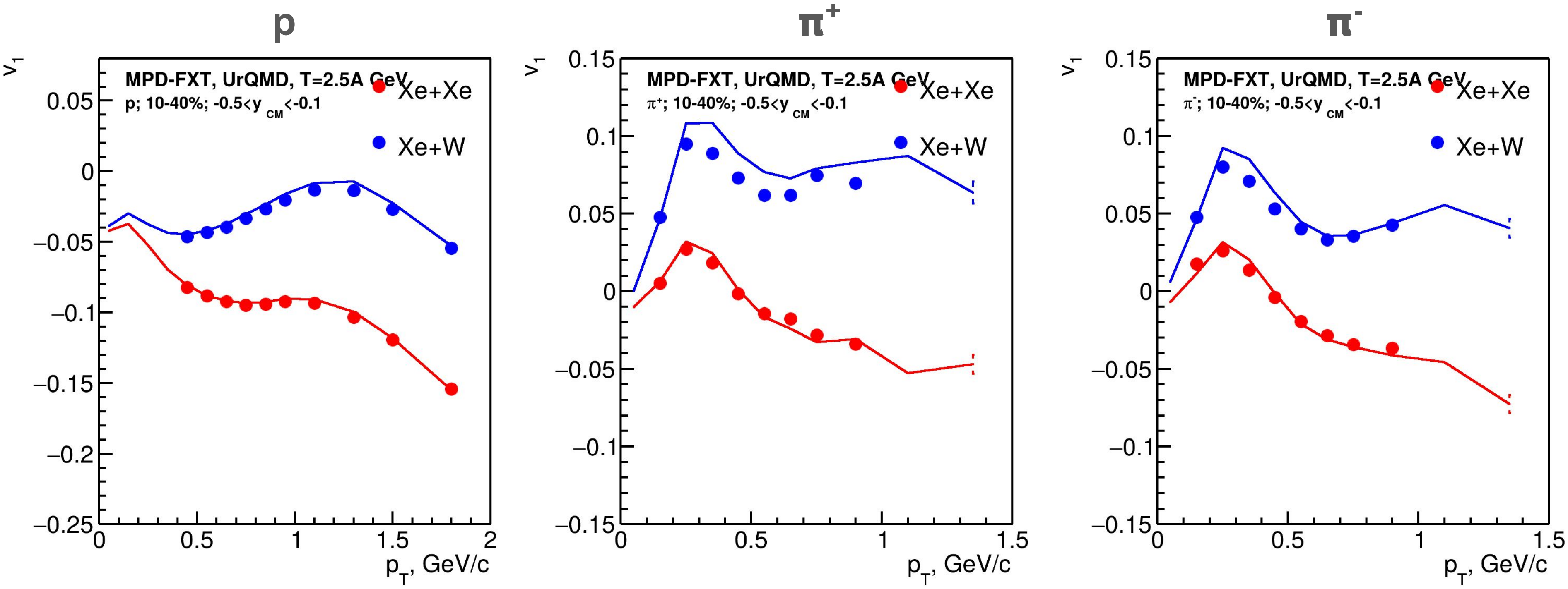
Systematics: xx, yy, F1, F2, F3



Protons - good. Discrepancy for pions: maybe we need a stricter PID/DCA cut?

Results: $v_1(p_T)$

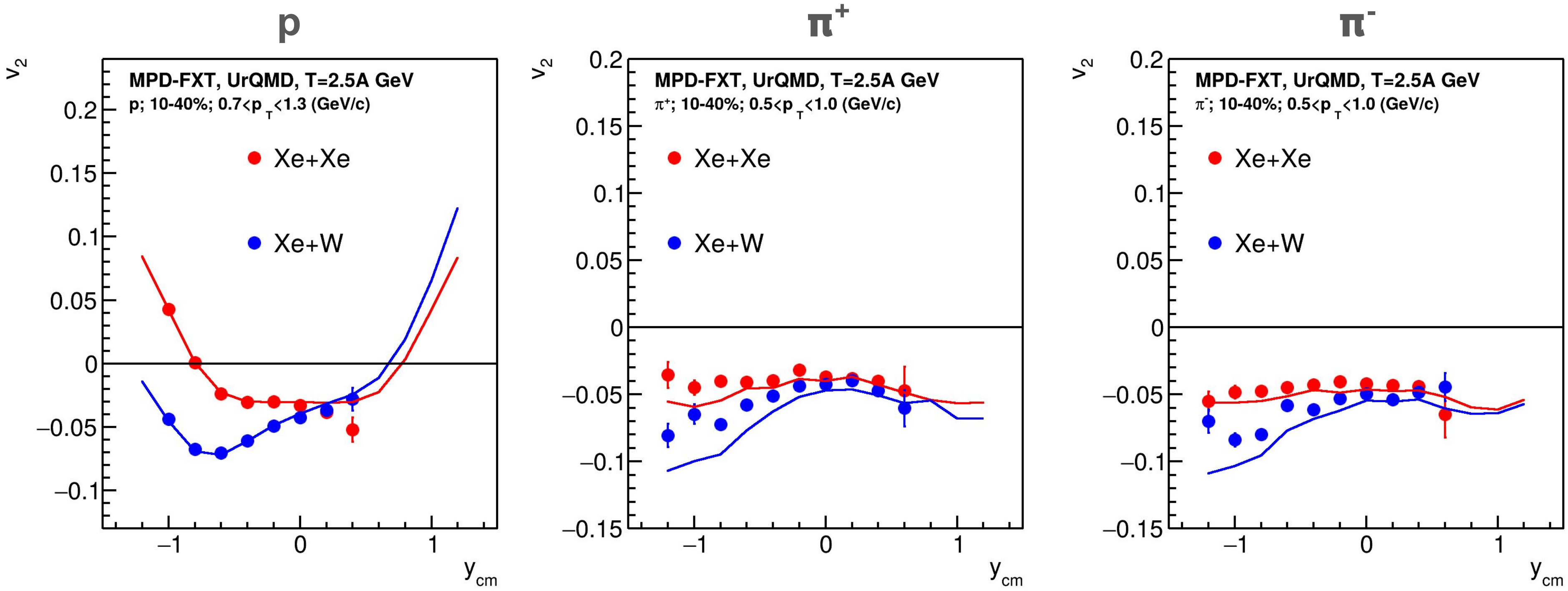
Systematics: xx, yy, F1, F2, F3



Protons - good. Discrepancy for pions: maybe we need a stricter PID/DCA cut?

Results: $v_2(y)$

Systematics: xxx, xyy



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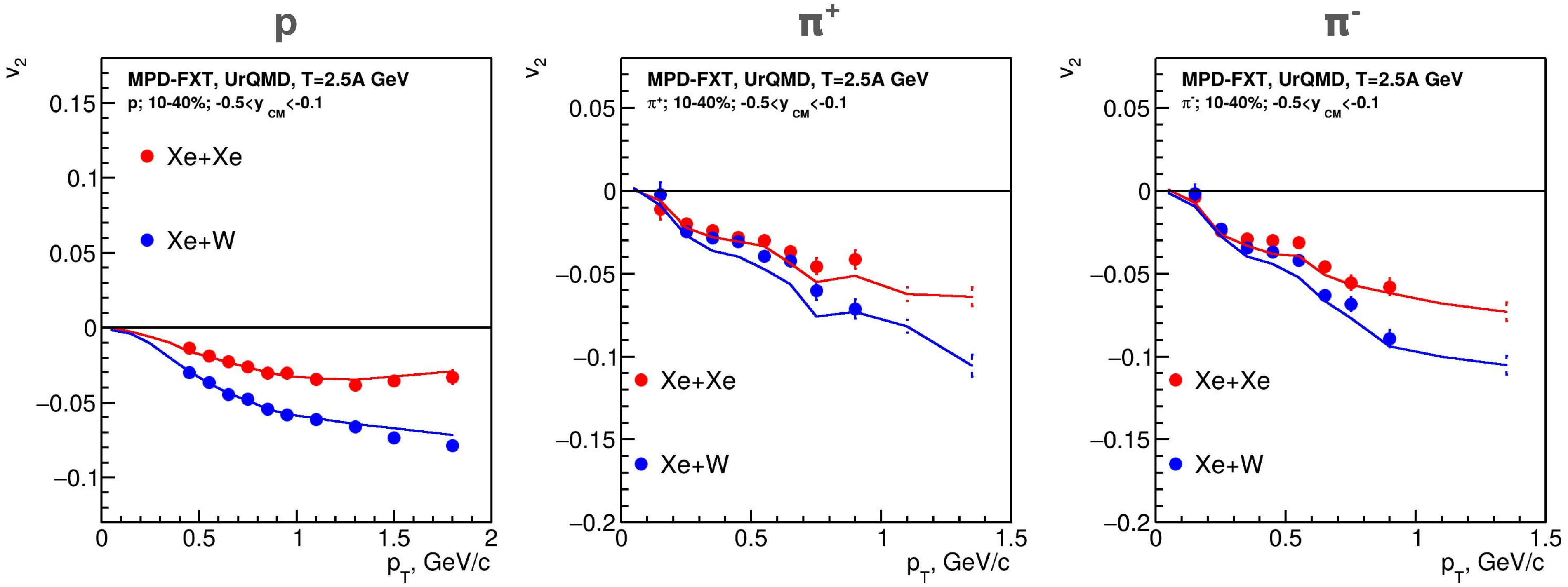
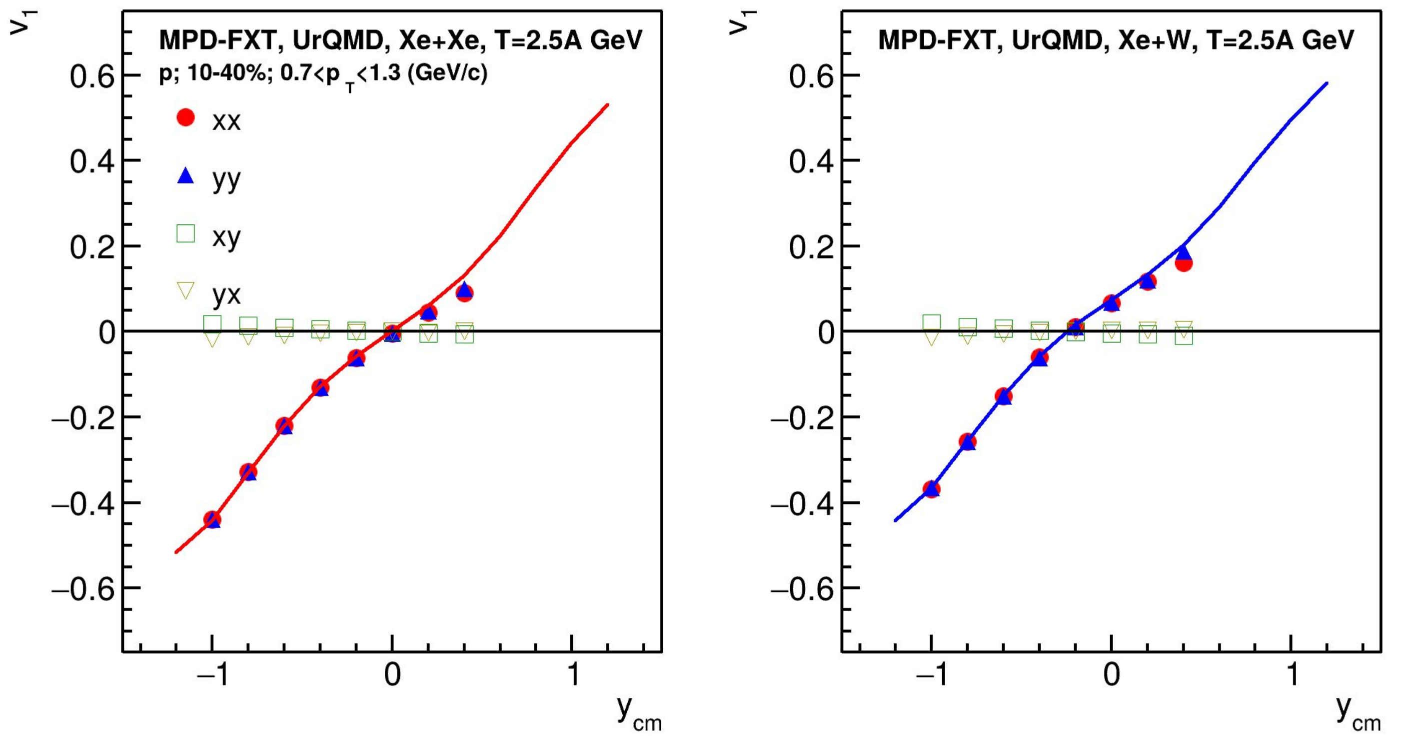


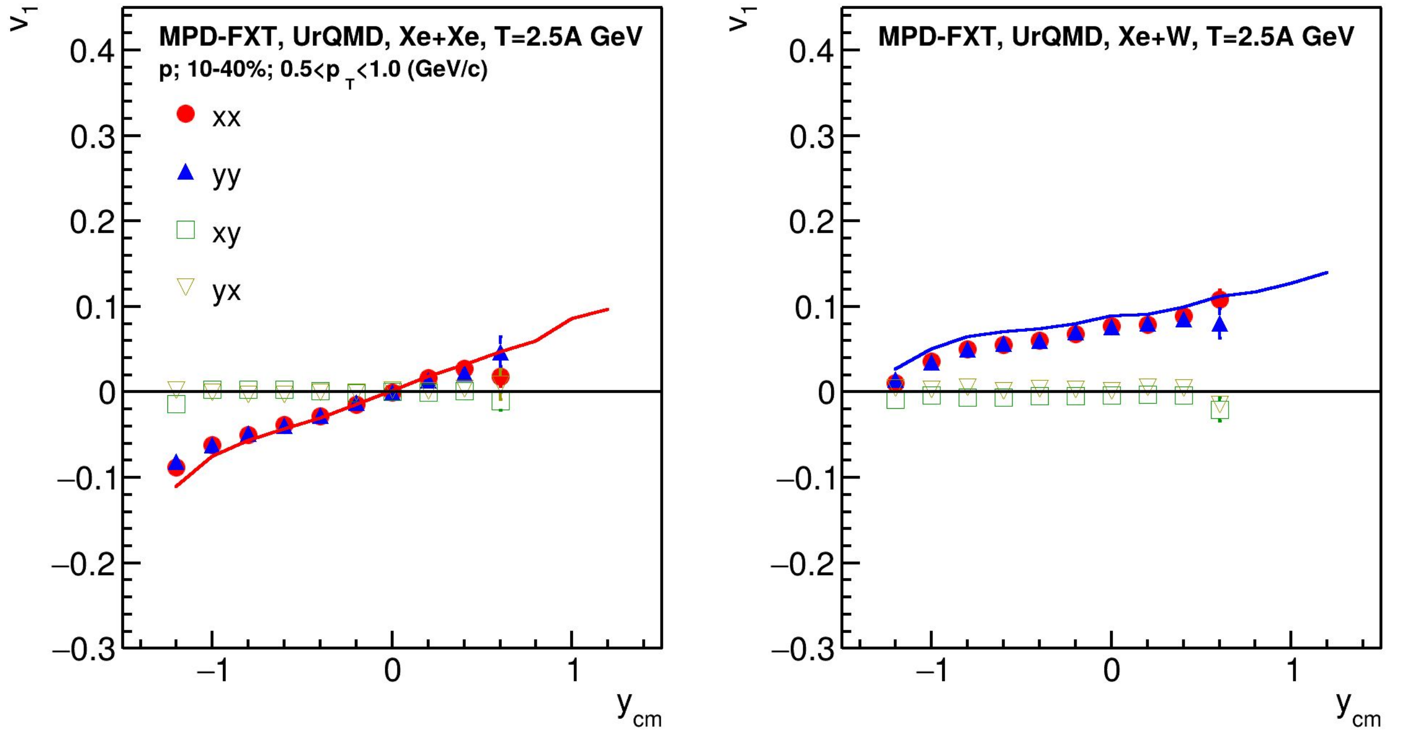
Protons - good. Discrepancy for pions: maybe we need a stricter PID/DCA cut?

$v_1(y)$ protons - components



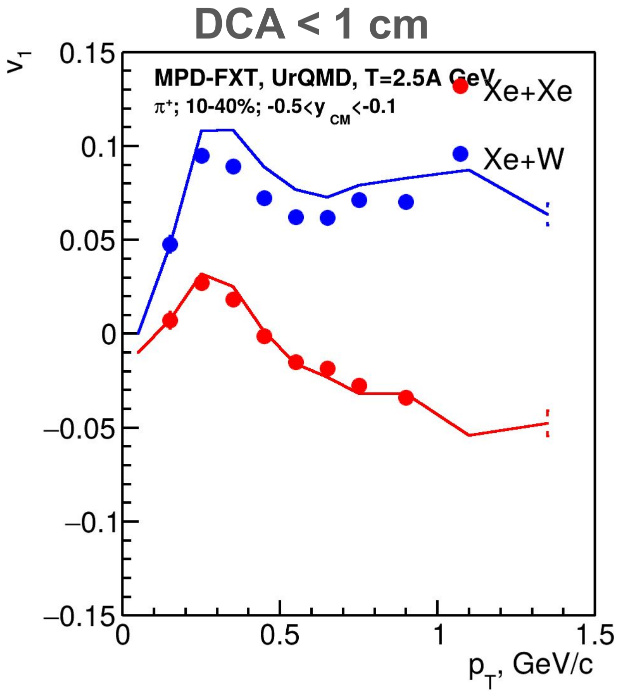
xx=yy, xy=yx=0. Looks ok for both Xe+Xe and Xe+W.

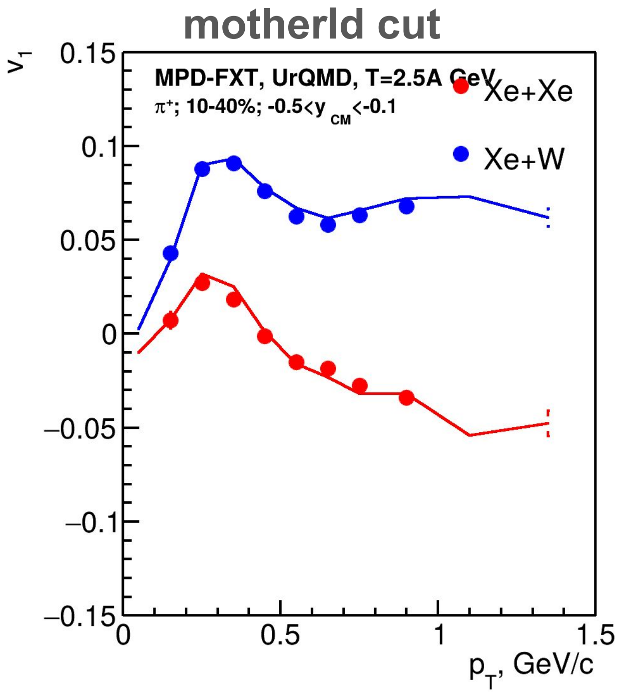
$v_1(y)$ π^+ - components



xx=yy, xy=yx=0. Looks ok for both Xe+Xe and Xe+W.

Results v_1: pions problem in Xe+W (π^+)





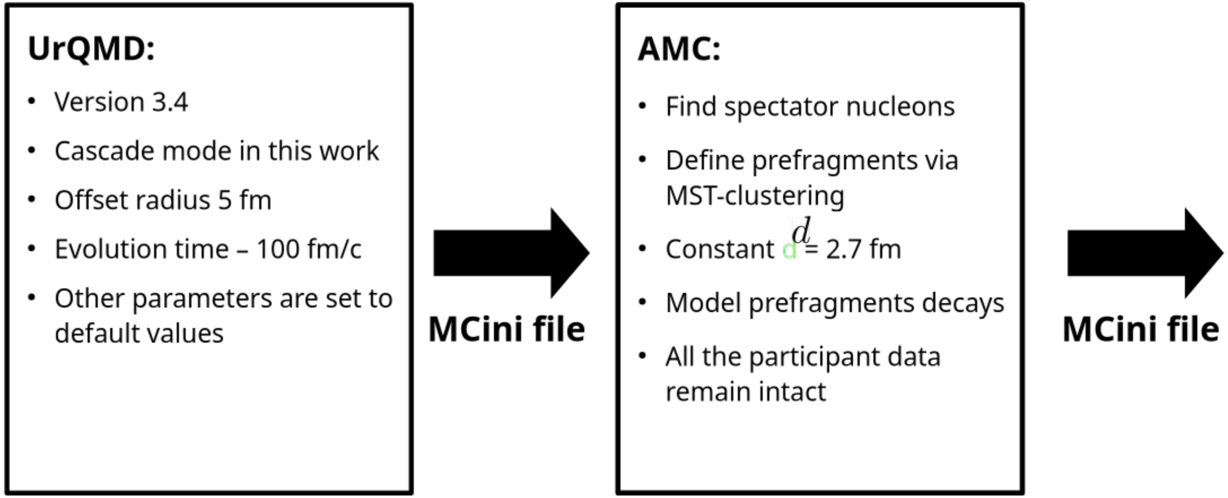
Difference between mc and reco for pions due to secondary particles

Secondary pions affect signal in Xe+W

https://github.com/Spectator-matter-group-INR-RAS/AAMCC

Combining UrQMD and AAMCC

- AMC is developed to simulate secondary decays of spectator fragments created in other models, in particular UrQMD.
- It is assumed that spectator matter is formed out of nucleons that do not undergo any collisions.



UrQMD and UrQMD-AAMCC: Data sets

Base model: UrQMD ver. 3.4

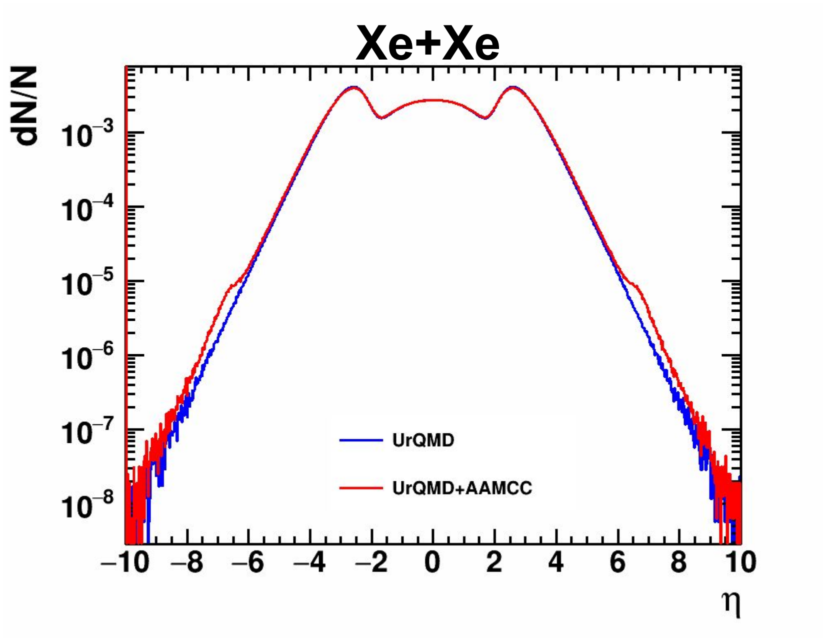
UrQMD configuration:

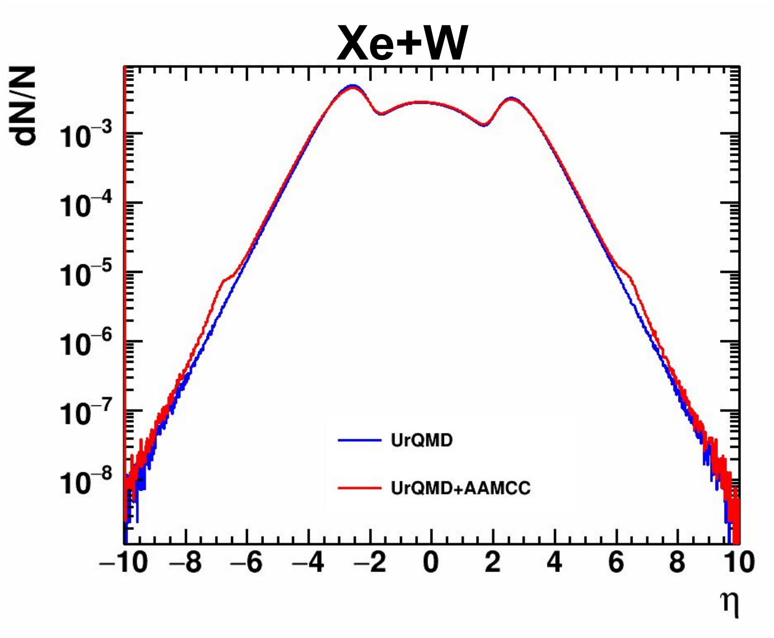
- Xe+Xe and Xe+W (2M events each)
- T=2.5A GeV (2.87 GeV)
- mean-field (Skyrme potential)

UrQMD-AAMCC configuration:

- Same UrQMD setup
- AAMCC in afterburner mode
  - Excitation energy of prefragment: hybrid density function is used based on Ericson formula and ALADIN parametrization

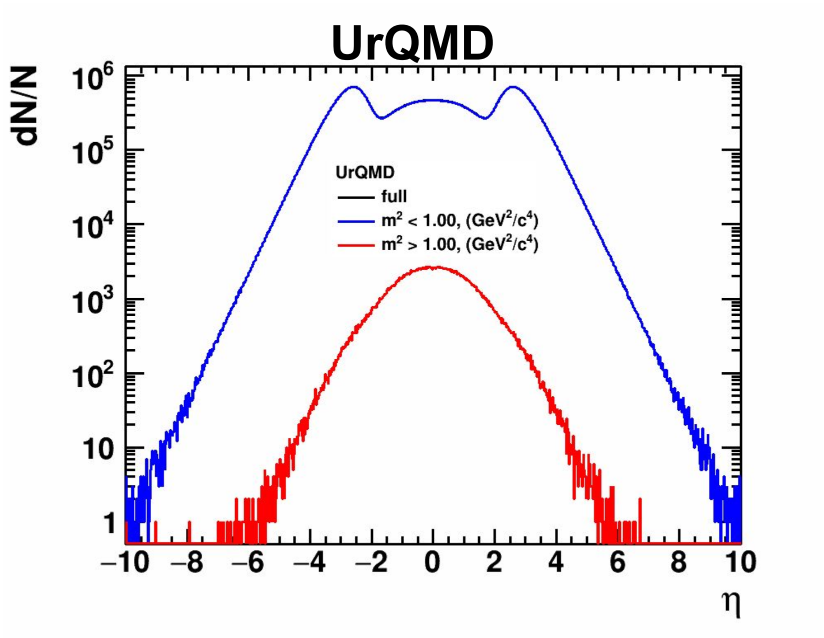
Pseudorapidity

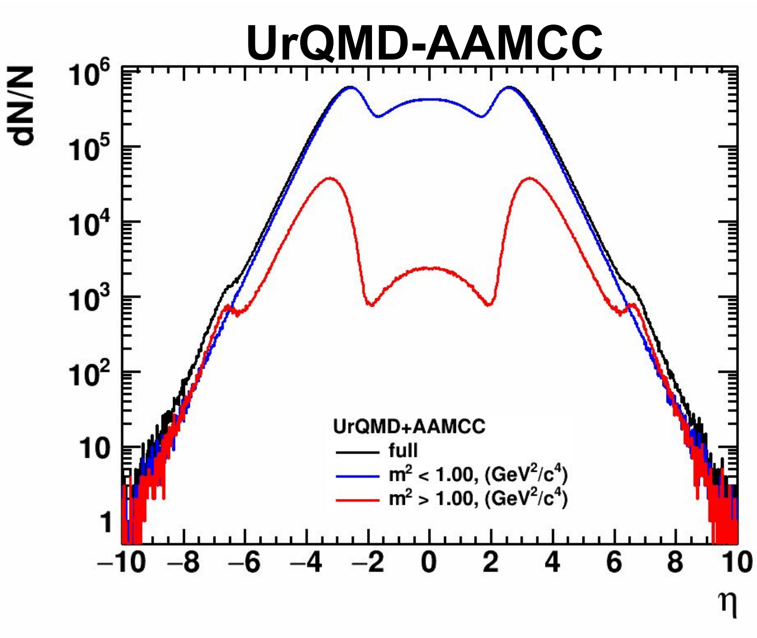




As expected, more particles (fragments) in the forward/backward η region

Pseudorapidity: different masses (Xe+Xe)

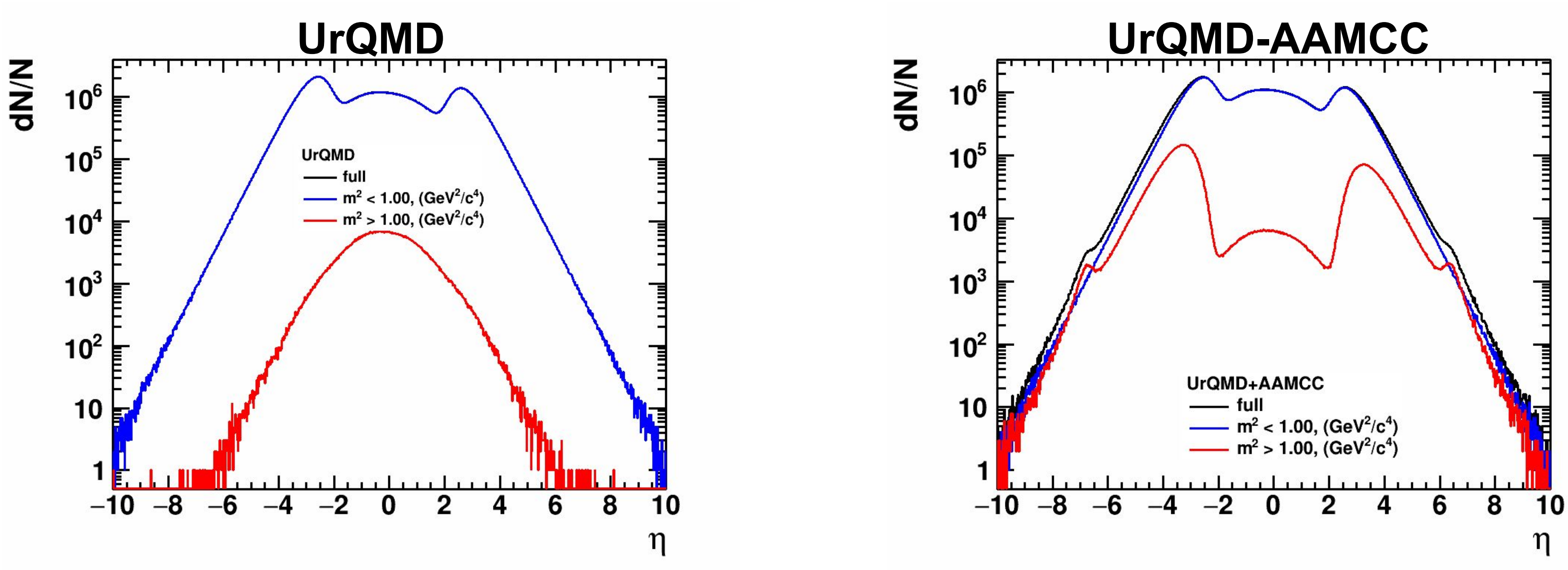




UrQMD: particle with m>1 GeV/c^2 are born in the participant region

UrQMD-AAMCC: large contribution from the spectator region (fragments)

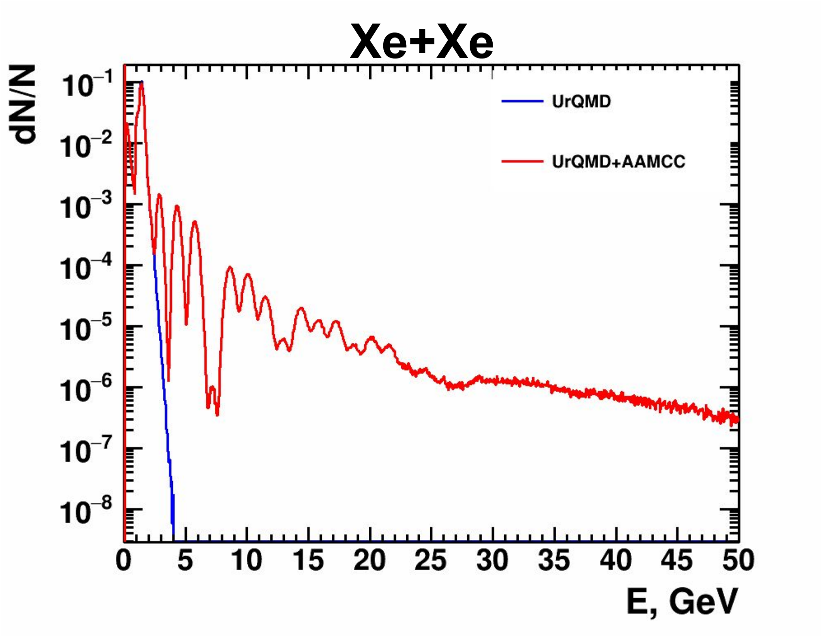
Pseudorapidity: different masses (Xe+W)

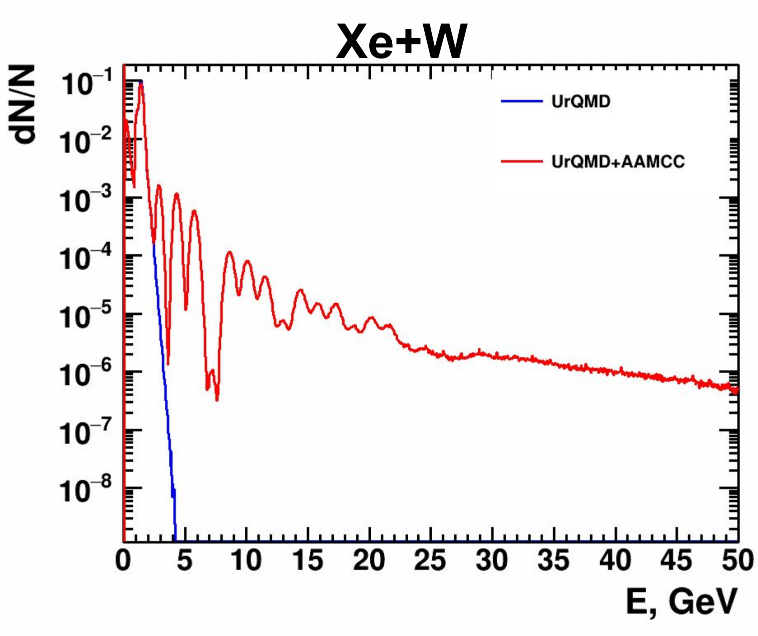


UrQMD: particle with m>1 GeV/c^2 are born in the participant region

UrQMD-AAMCC: large contribution from the spectator region (fragments)

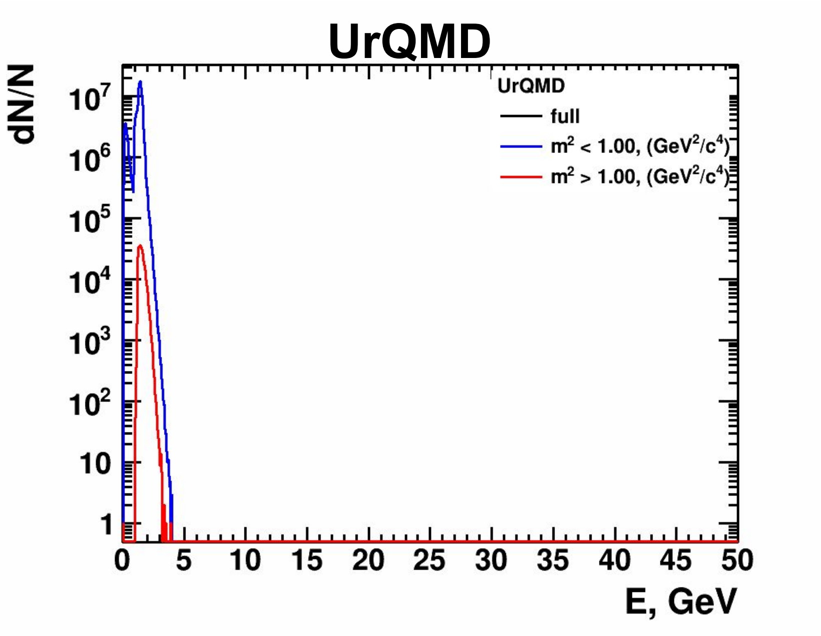
Energy (of the particles)

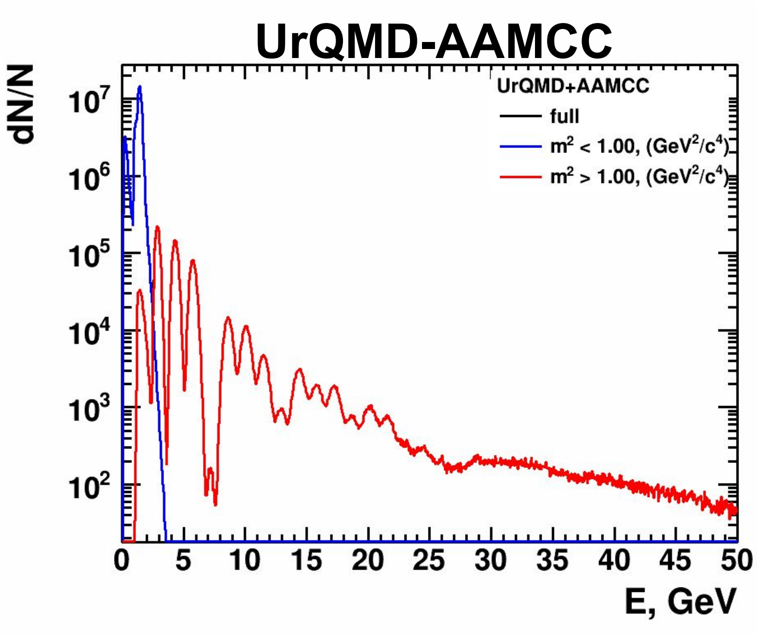




As expected, AAMCC adds particles (fragments) with higher energy

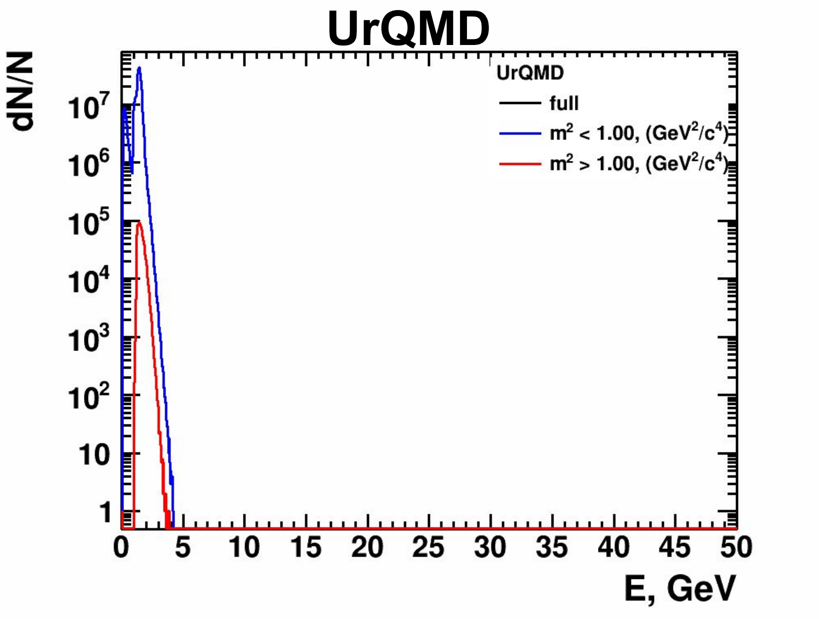
Energy: different masses (Xe+Xe)

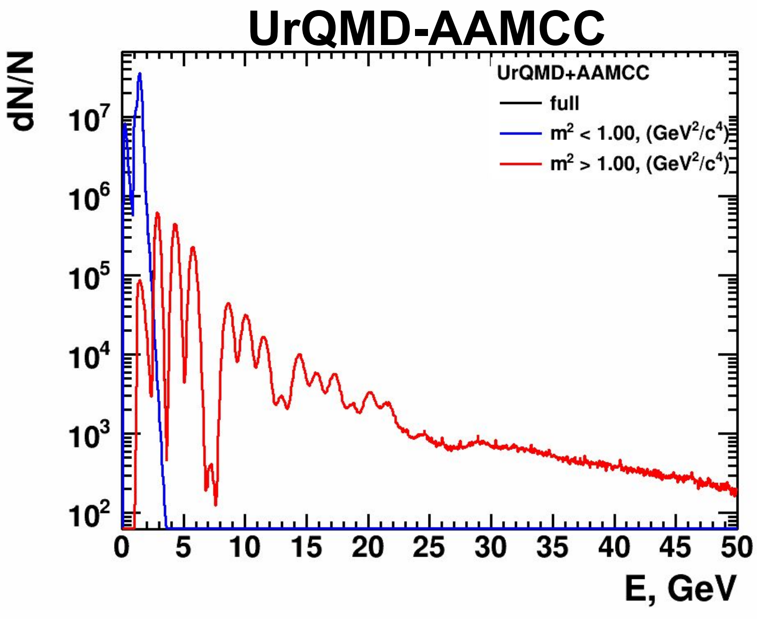




As expected, particles with higher energies are coming from AAMCC (fragments)

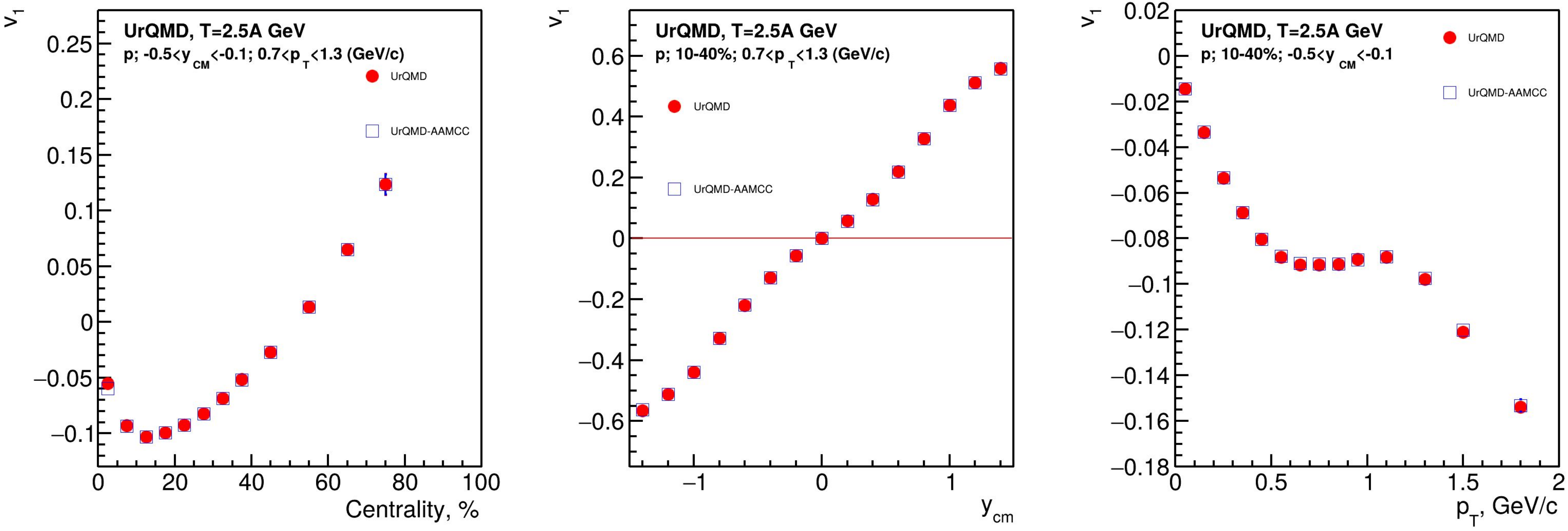
Energy: different masses (Xe+W)





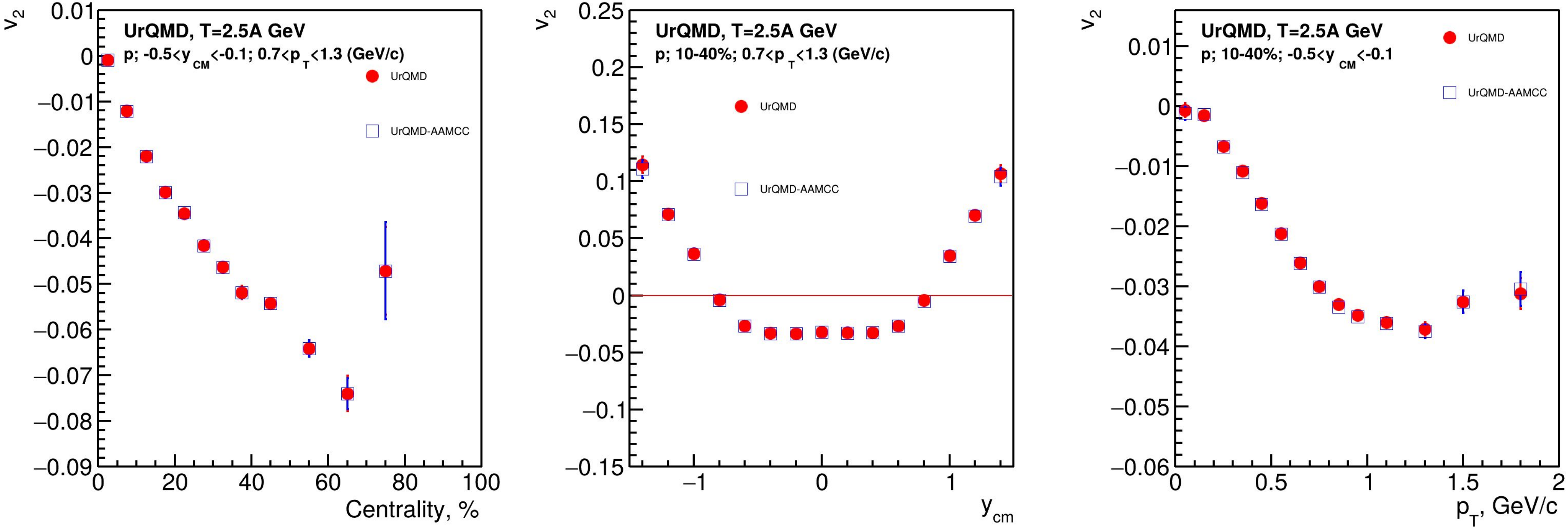
As expected, more particles with m>1 GeV/c^2 in UrQMD-AAMCC compared to UrQMD

Directed flow: UrQMD vs UrQMD-AAMCC (protons)



There are no difference in v_1 for UrQMD and UrQMD-AAMCC

Elliptic flow: UrQMD vs UrQMD-AAMCC (protons)



There are no difference in v_2 for UrQMD and UrQMD-AAMCC

Summary

- **v1, v2 of protons and pions in Xe+Xe, Xe+W, T=2.5A GeV**
    - Realistic procedures for centrality determination, primary track selection and PID were used
        - Multiplicity-based centrality determination using MC-Glauber was used
    - Basic PID was performed using dE/dx from TPC and m^2 from TOF
    - Good agreement between “reco” and “mc” within corresponding acceptance window for protons
    - Discrepancy between “reco” and “mc” for pions are due to secondary particles: dca<1 cm cut is not enough for Xe+W
- **UrQMD vs. UrQMD-AAMCC**
    - Expected differences between UrQMD and UrQMD-AAMCC due to the presence of the fragments in the latter model
    - No fundamental differences between data sets for Xe+Xe and Xe+W
    - Difference between UrQMD and UrQMD-AAMCC is negligible in terms of anisotropic flow

Backup

Ablation Monte Carlo: decay code from AAMCC

The excited nuclear fragments are formed by means of MST-clusterization algorithm

The excited nuclear clusters – prefragments is modelled by MST-clustering in coordinate space, in contrast with DCM-QGSM-SMM, where all the spectator nucleon remain bound in one prefragment.

Excitation energy of prefragment is calculated by hybrid approximation: a combination of Ericson formula for peripheral collisions and ALADIN approximation otherwise[1)]

Decays of prefragments are simulated as follows:

Fermi break-up model from Geant4 v9.2 [2)]

Statistical Multifragmentation Model (SMM) from Geant4 v10.4 [2)]

Weisskopf-Ewing evaporation model

from Geant4 v10.4 [2)]

They were validated and adjusted to describe the data[3)].

1) R. Nepeivoda, et al., Particles 5 (2022) 40

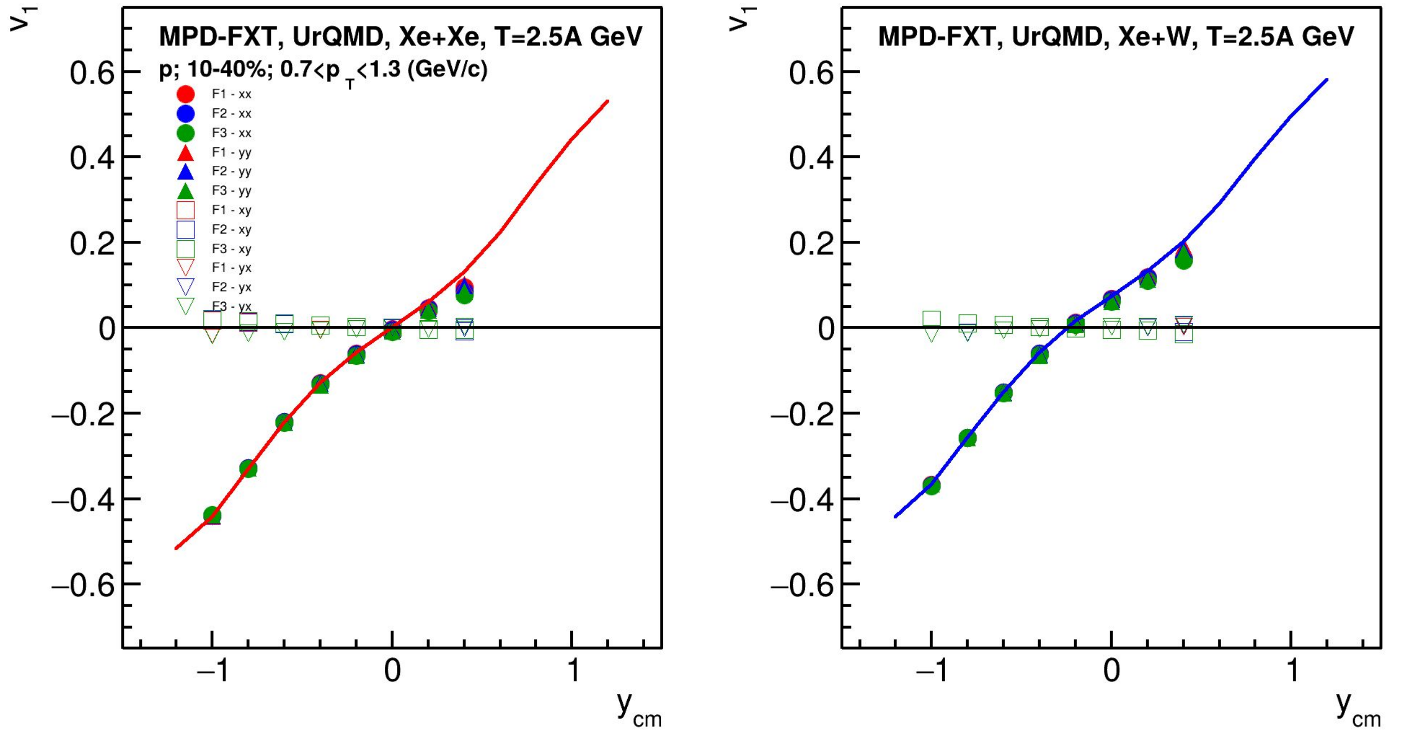
2) J. Alison et al. Nucl. Inst. A 835 (2016) 186

3) 55th Geant4 Techical Forum

https://indico.cern.ch/event/1106118/contributions/4693132/

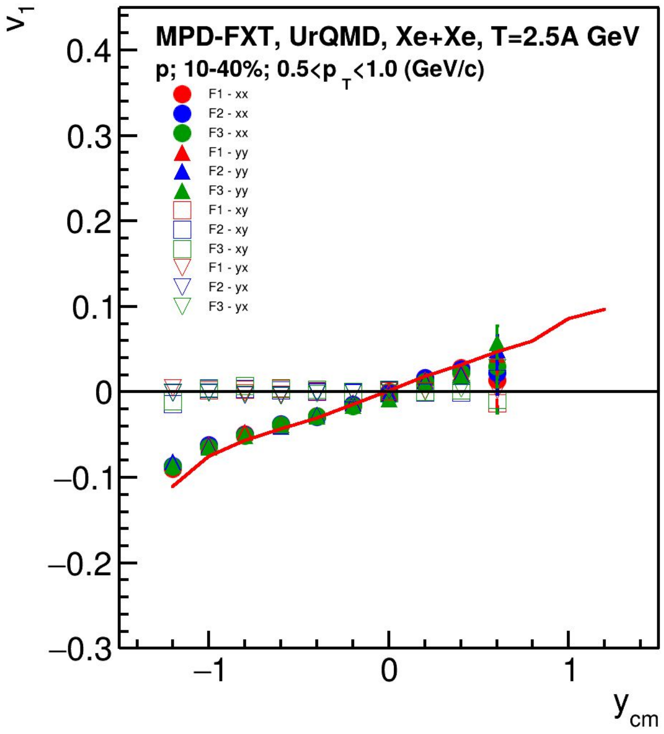
https://github.com/Spectator-matter-group-INR-RAS/AAMCC

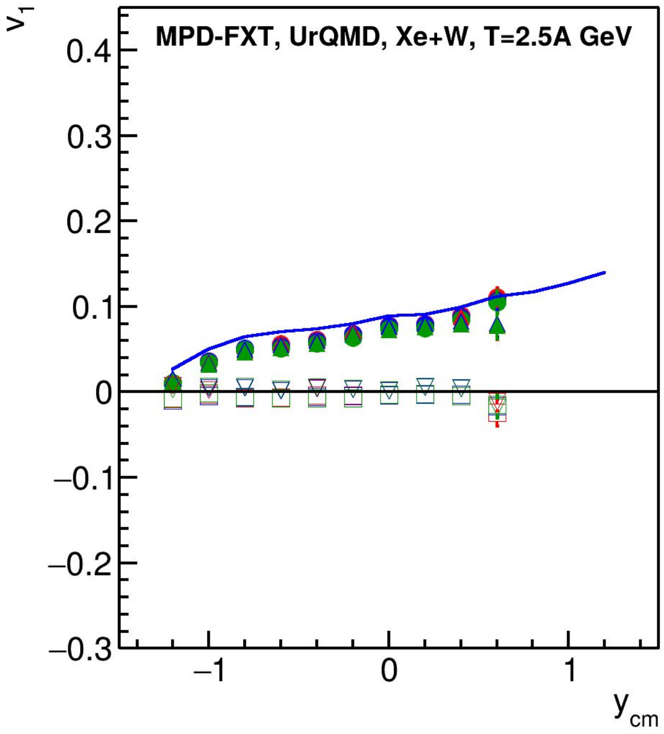
v_1(y) protons - components, detailed look



xx=yy, xy=yx=0. Looks ok for both Xe+Xe and Xe+W.

$v_1(y)$ π^+ - components, detailed look

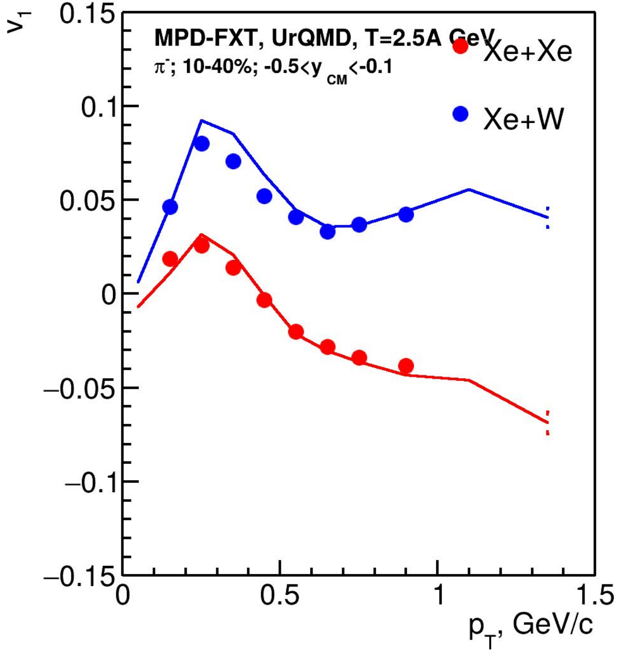




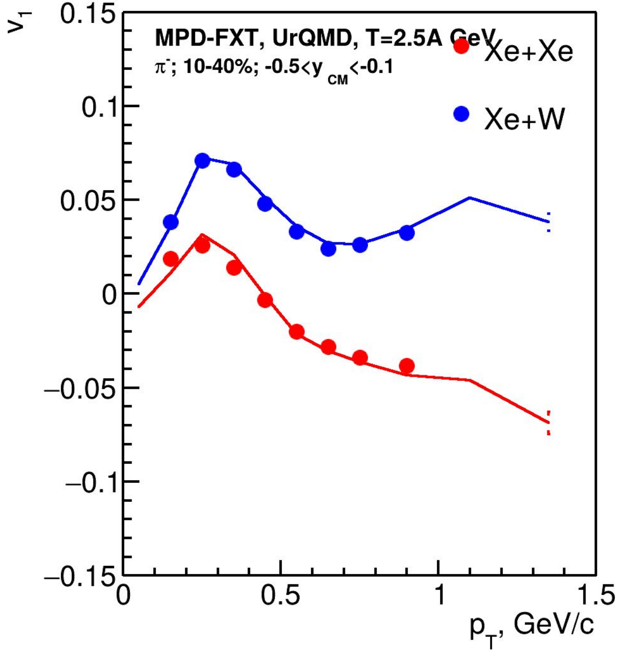
xx=yy, xy=yx=0. Looks ok for both Xe+Xe and Xe+W.

Results v_1: pions problem in Xe+W (π^-)

DCA < 1 cm



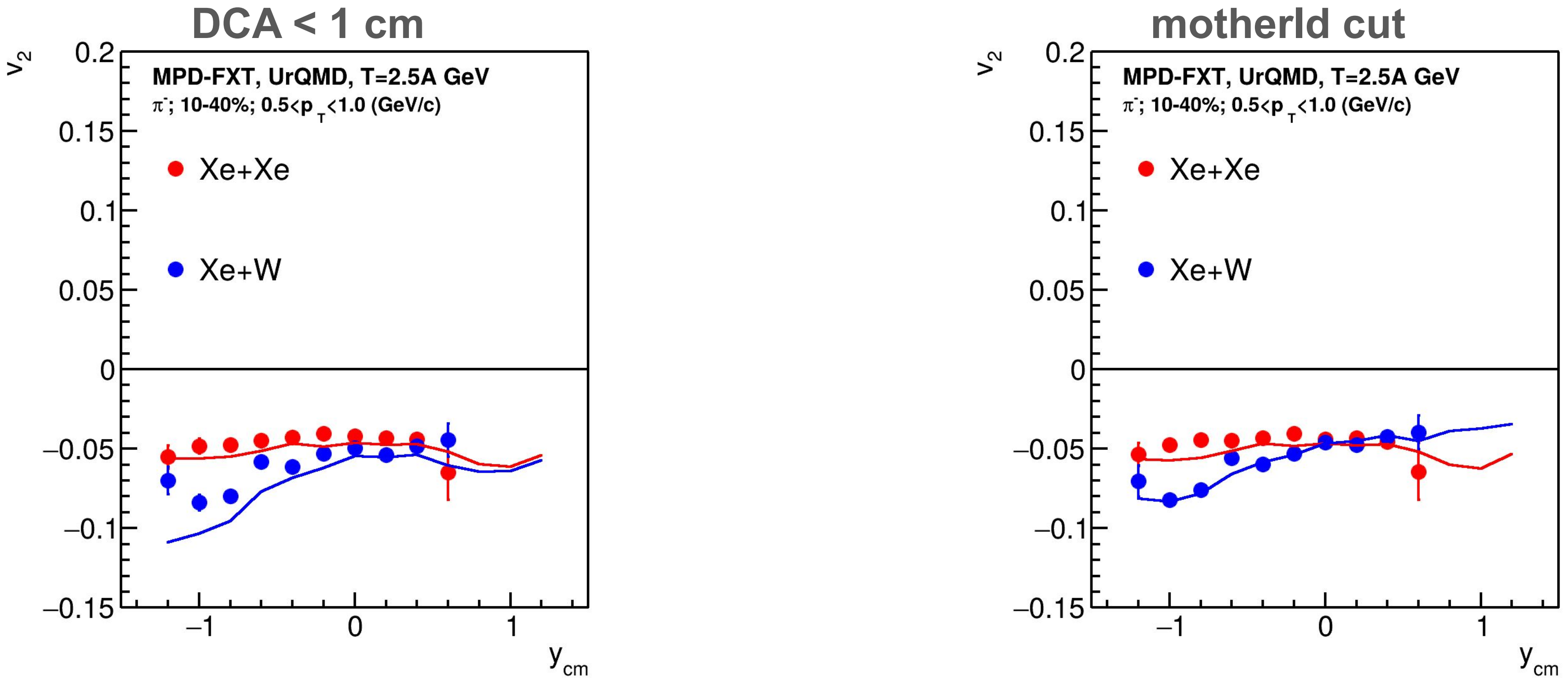
motherId cut



Difference between mc and reco for pions due to secondary particles

Secondary pions affect signal in Xe+W

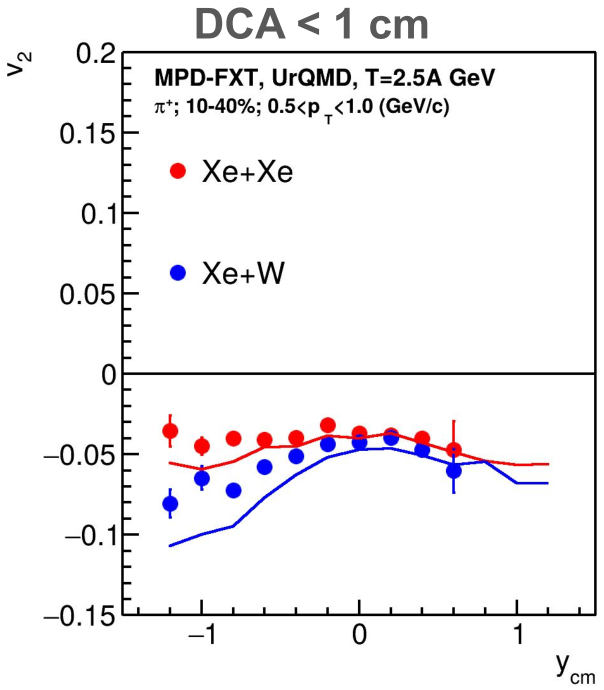
Results v_2: pions problem in Xe+W (π^-)

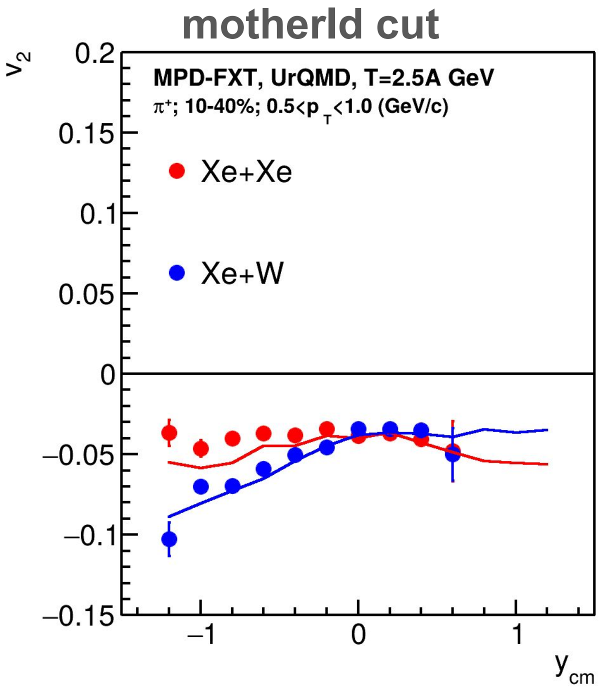


Difference between mc and reco for pions due to secondary particles

Secondary pions affect signal in Xe+W

Results v_2: pions problem in Xe+W (π^+)

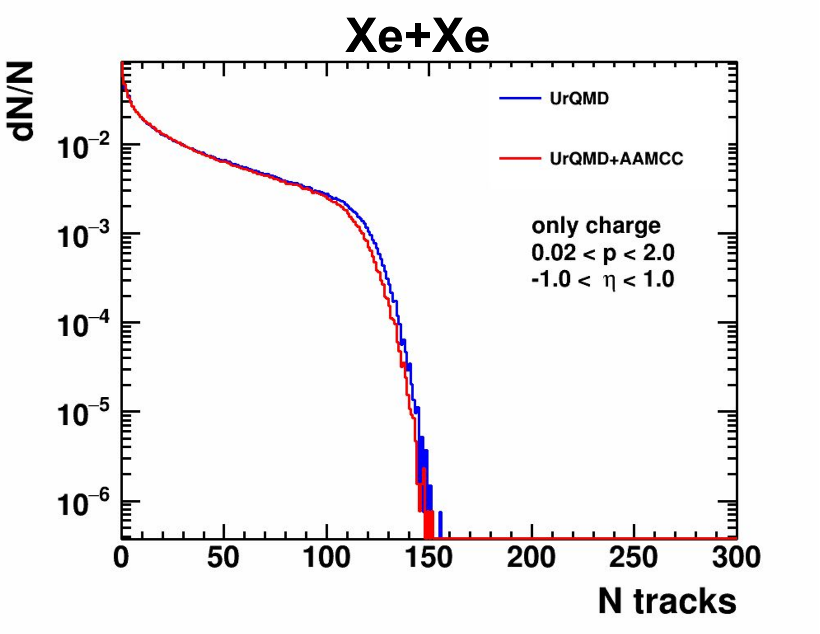


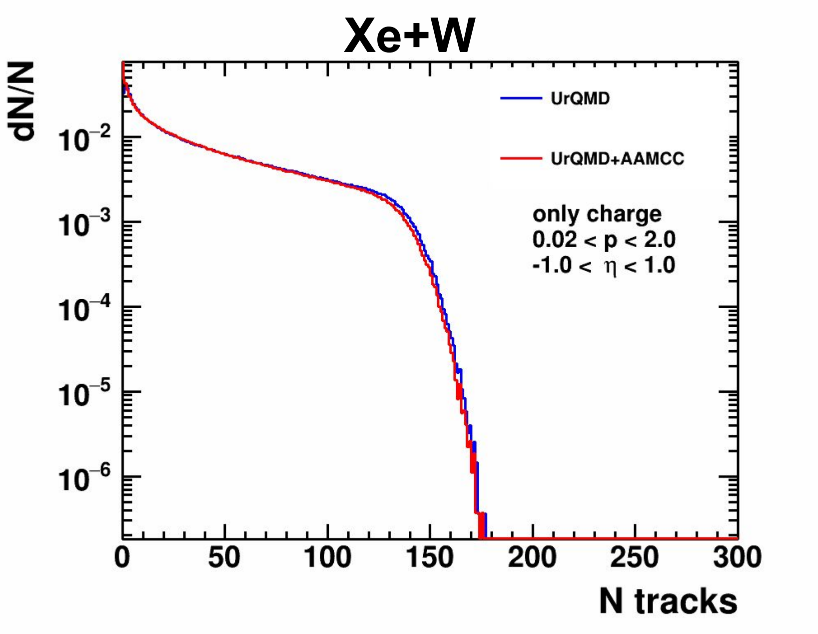


Difference between mc and reco for pions due to secondary particles

Secondary pions affect signal in Xe+W

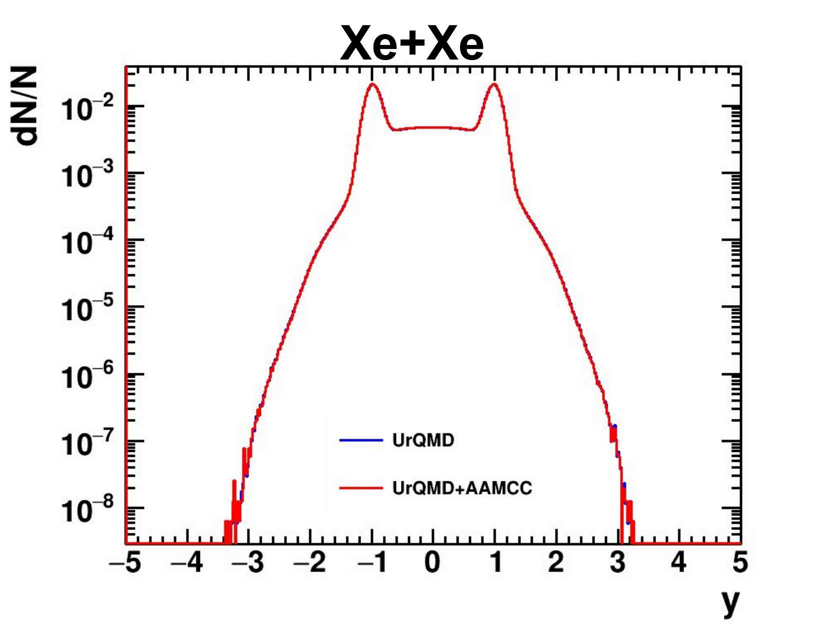
Charge particle multiplicity

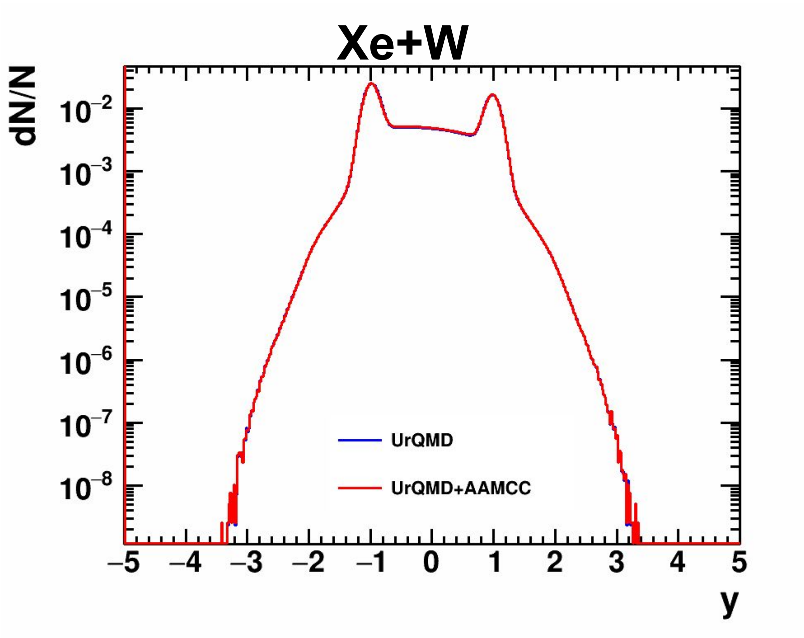




Difference between UrQMD and UrQMD-AAMCC is visibly smaller for larger systems

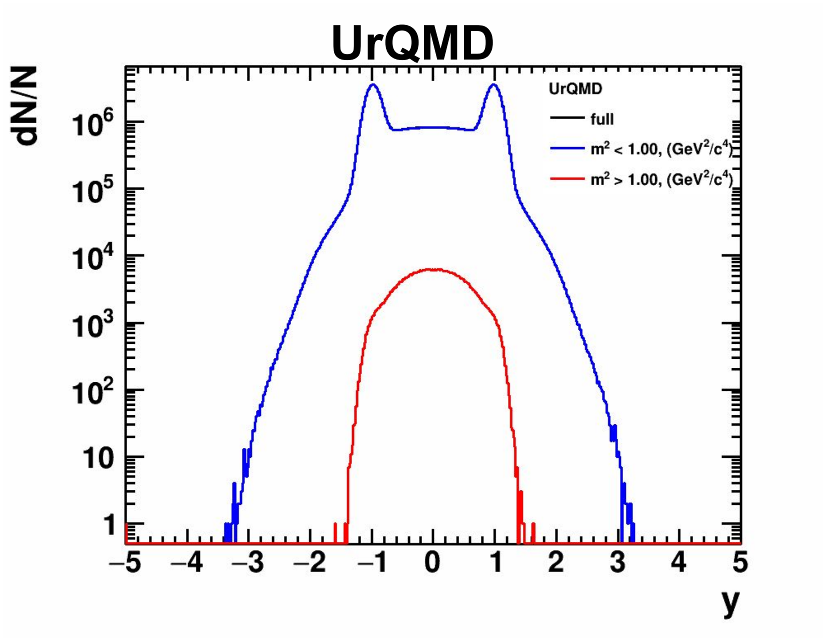
Rapidity

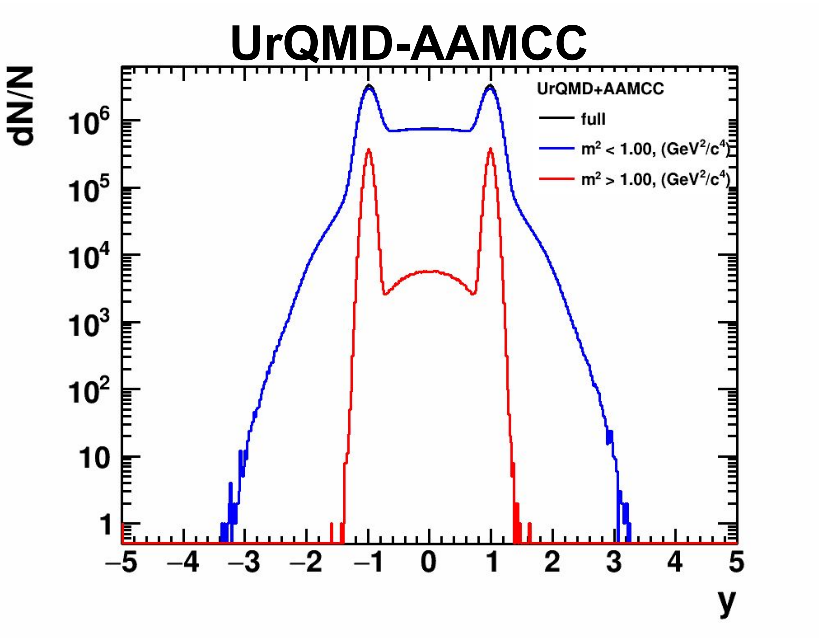




No noticeable difference in y

Rapidity: different masses (Xe+Xe)

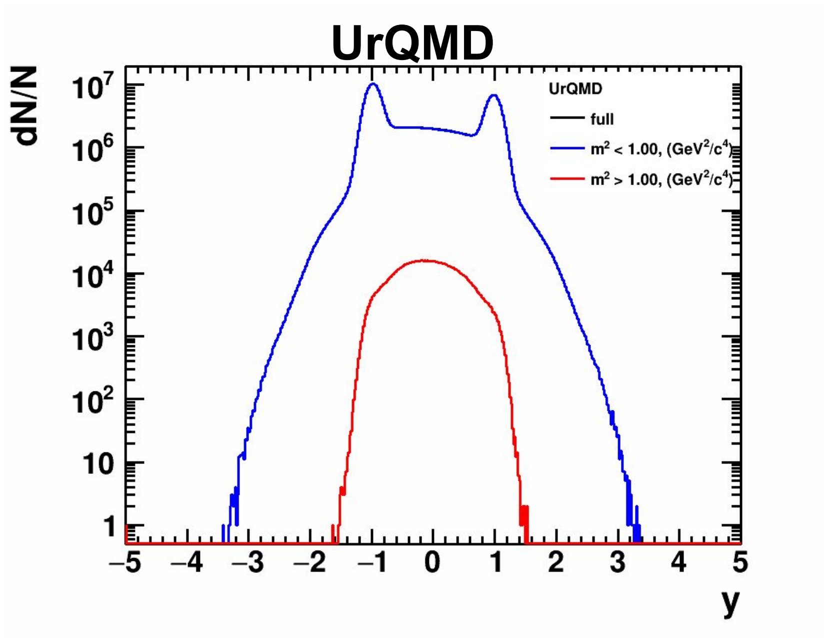


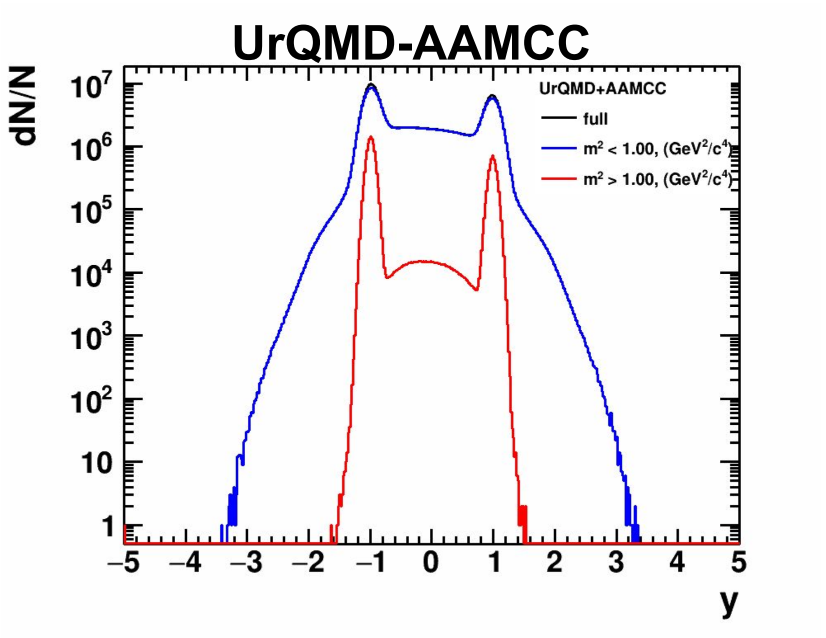


UrQMD: particle with m>1 GeV/c^2 are born in the participant region

UrQMD-AAMCC: large contribution from the spectator region (fragments)

Rapidity: different masses (Xe+W)

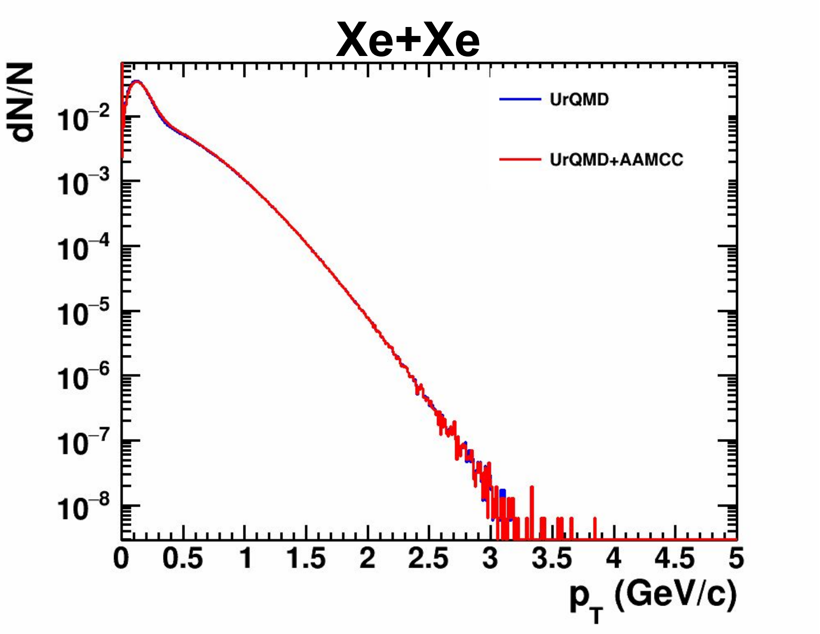


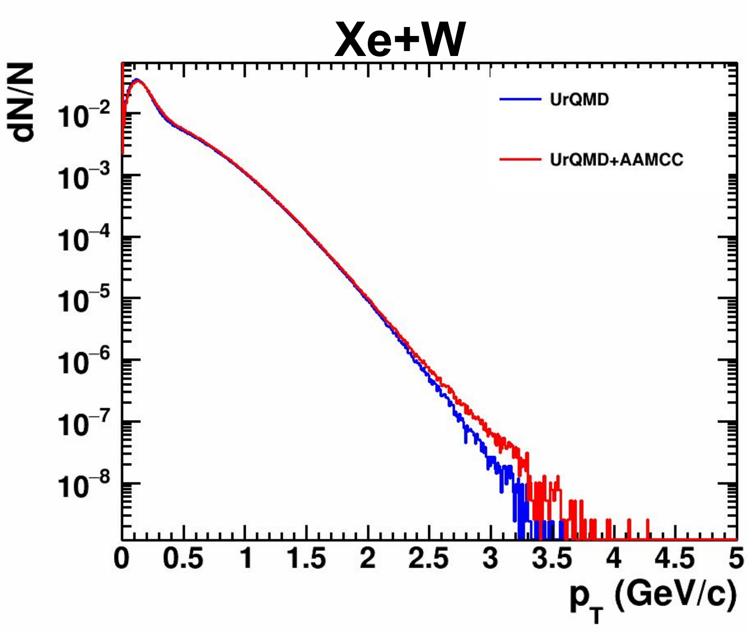


UrQMD: particle with m>1 GeV/c^2 are born in the participant region

UrQMD-AAMCC: large contribution from the spectator region (fragments)

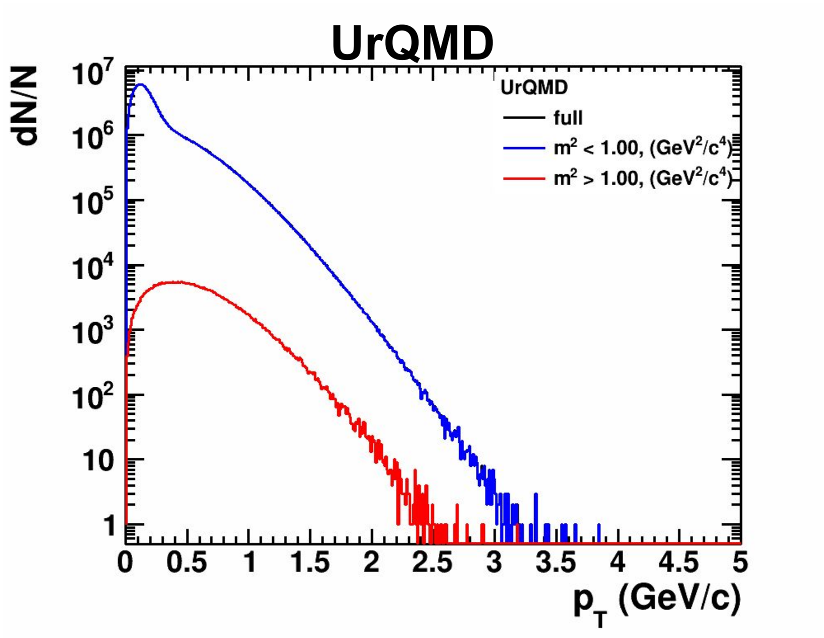
Transverse momentum

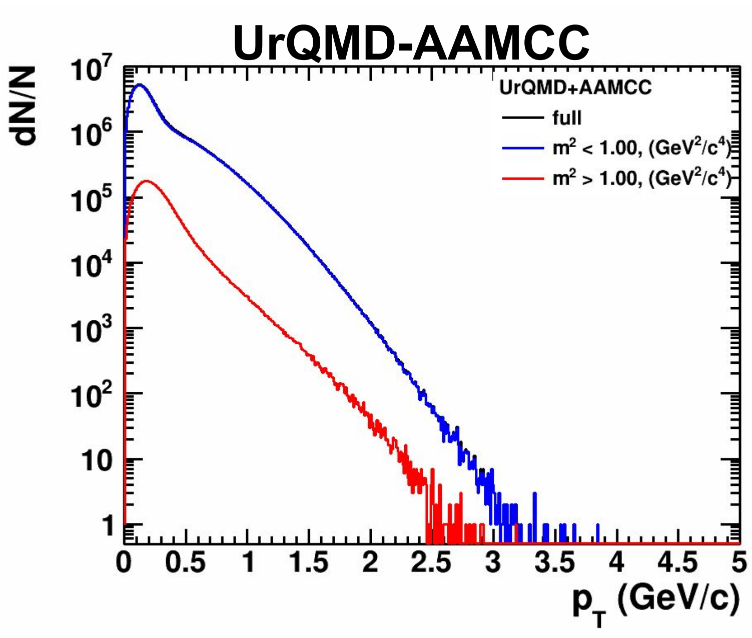




No noticeable difference in p_T for Xe+Xe, small difference for Xe+W at high p_T

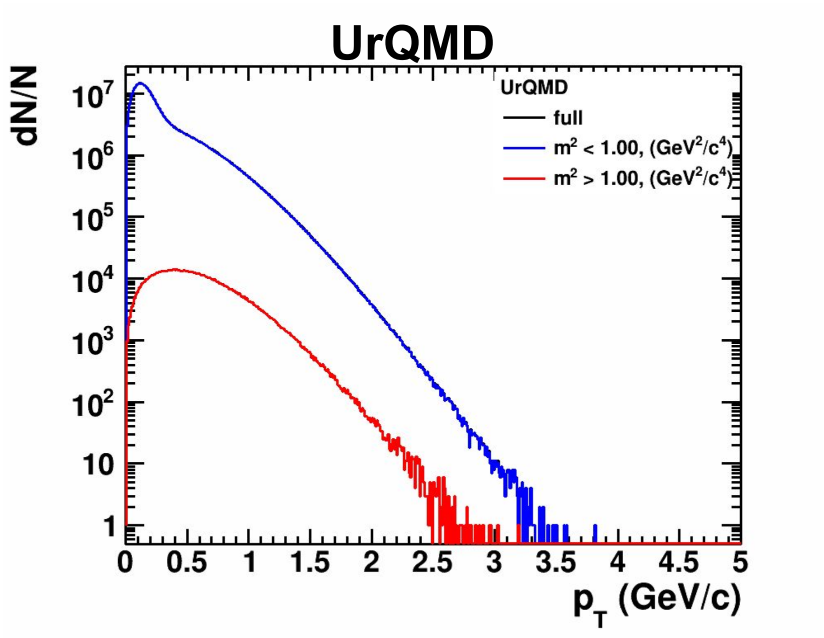
Transverse momentum: different masses (Xe+Xe)

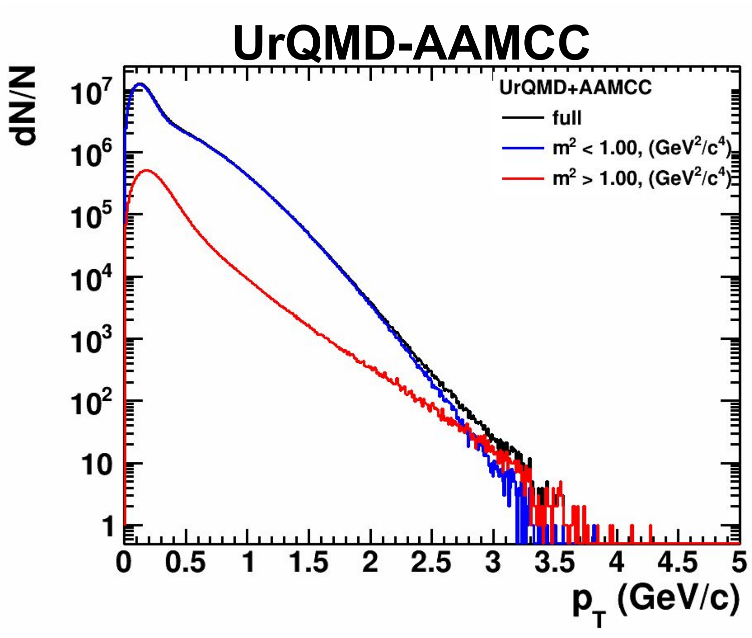




As expected, more particles with m>1 GeV/c^2 in UrQMD-AAMCC compared to UrQMD

Transverse momentum: different masses (Xe+W)





As expected, more particles with m>1 GeV/c^2 in UrQMD-AAMCC compared to UrQMD