Update on the flow measurements in the MPD-FXT configuration and initial geometry in asymmetric collisions

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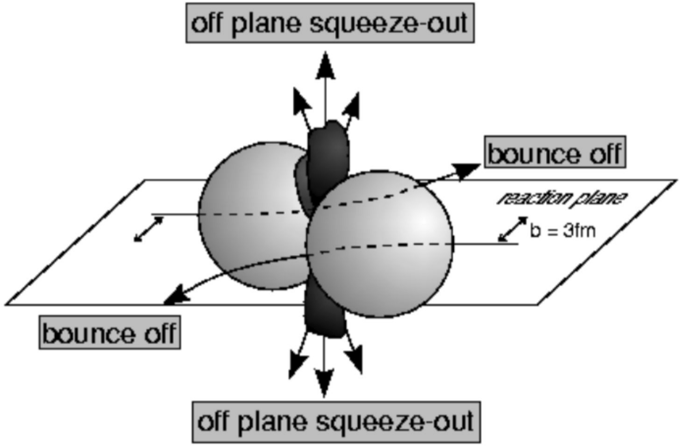
Update on the v_n measurements in MPD-FXT

Anisotropic flow & spectators



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

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

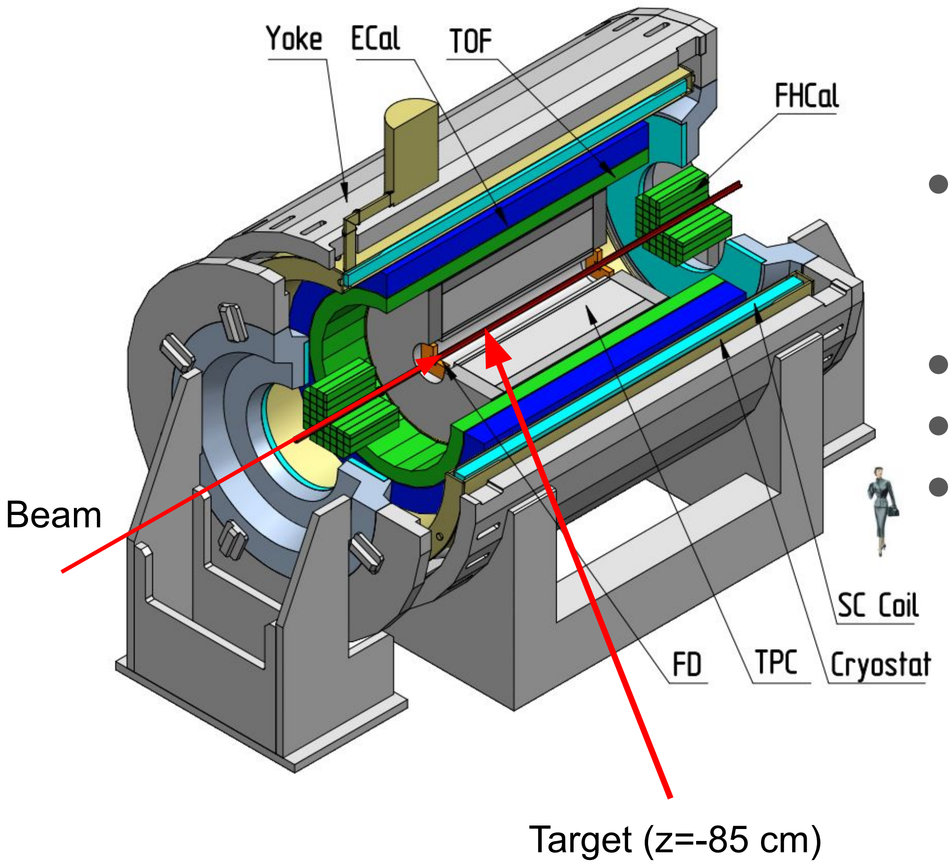
Anisotropic flow:

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

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:

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

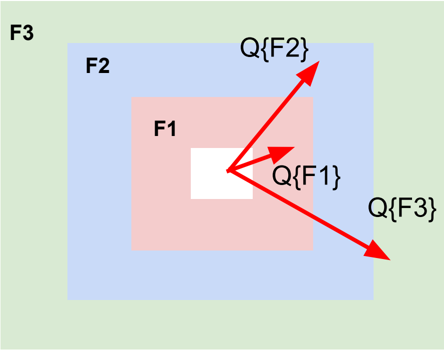
where φ is the azimuthal angle

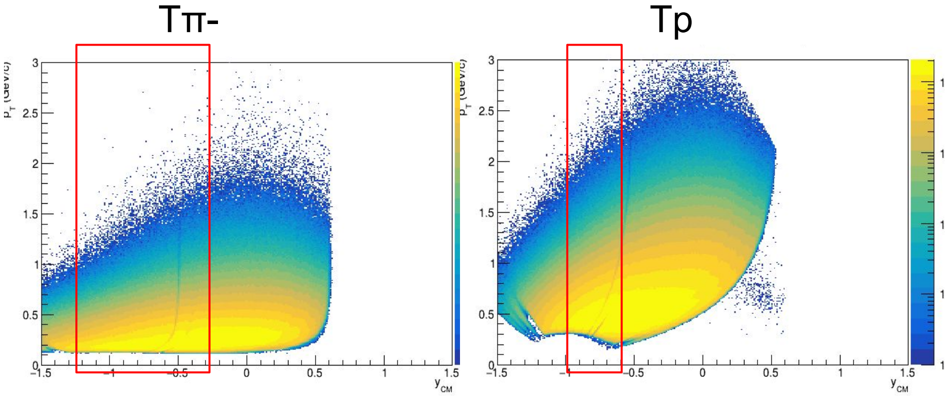
Sum over a group of u_n-vectors in one event forms Q_n-vector:

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

Ψ_n^{EP} is the event plane angle

Modules of FHCal divided into 3 groups





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:

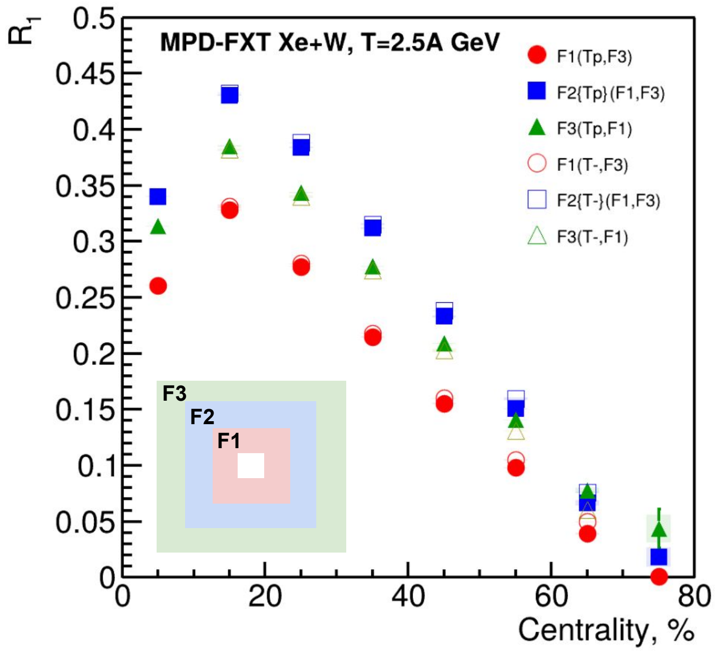
$$v_1 = \frac{\langle u_1 Q_1^{F1} \rangle}{R_1^{F1}} \qquad v_2 = \frac{\langle u_2 Q_1^{F1} Q_1^{F3} \rangle}{R_1^{F1} R_1^{F3}}$$

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):

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

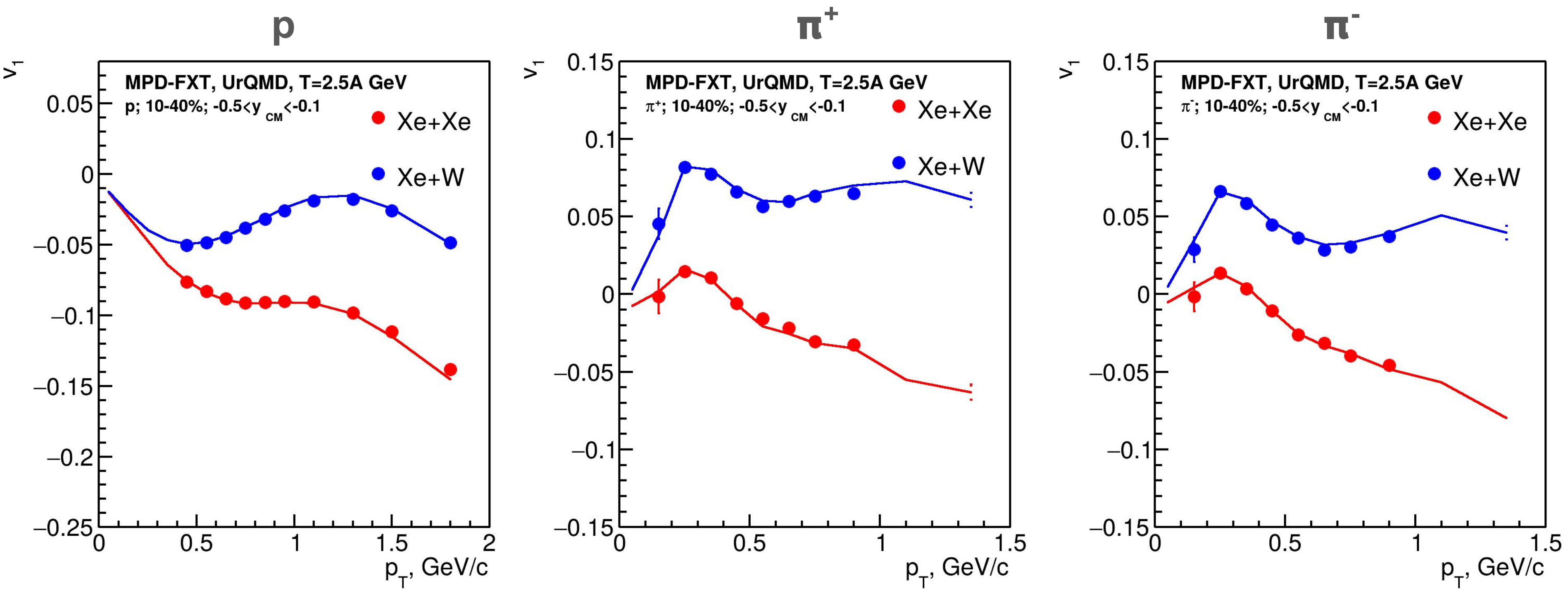


Symbol "F2{Tp}(F1,F3)" means R_1 calculated via (4S resolution):

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

Previously: v_n of $\pi^{\pm}$ is fixed, but…

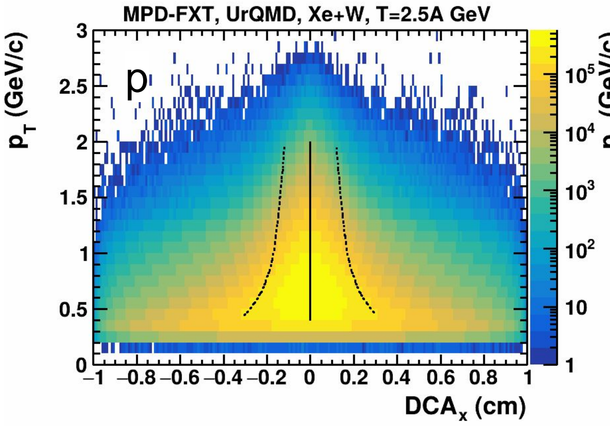
markers - reco; lines - model

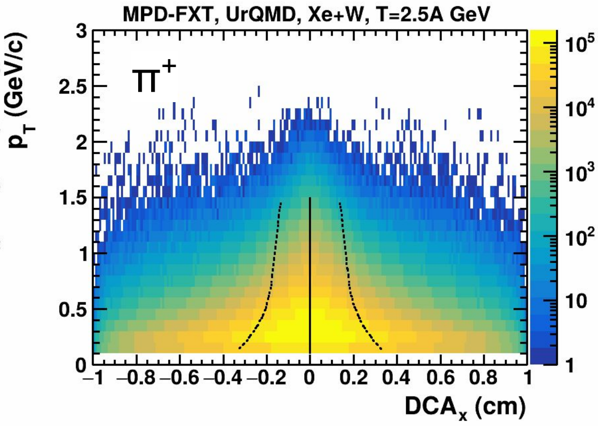


Strict fixed DCA cut (|DCA|<0.2 cm) fixes results for pions in Xe+W

However, it is better to use DCA cuts based on the n-σ distributions vs. p_T

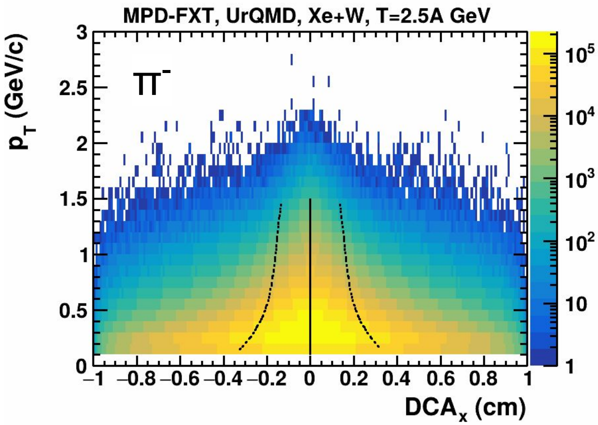
nσ DCA cut





The procedure is simple and similar to the PID nσ cuts:

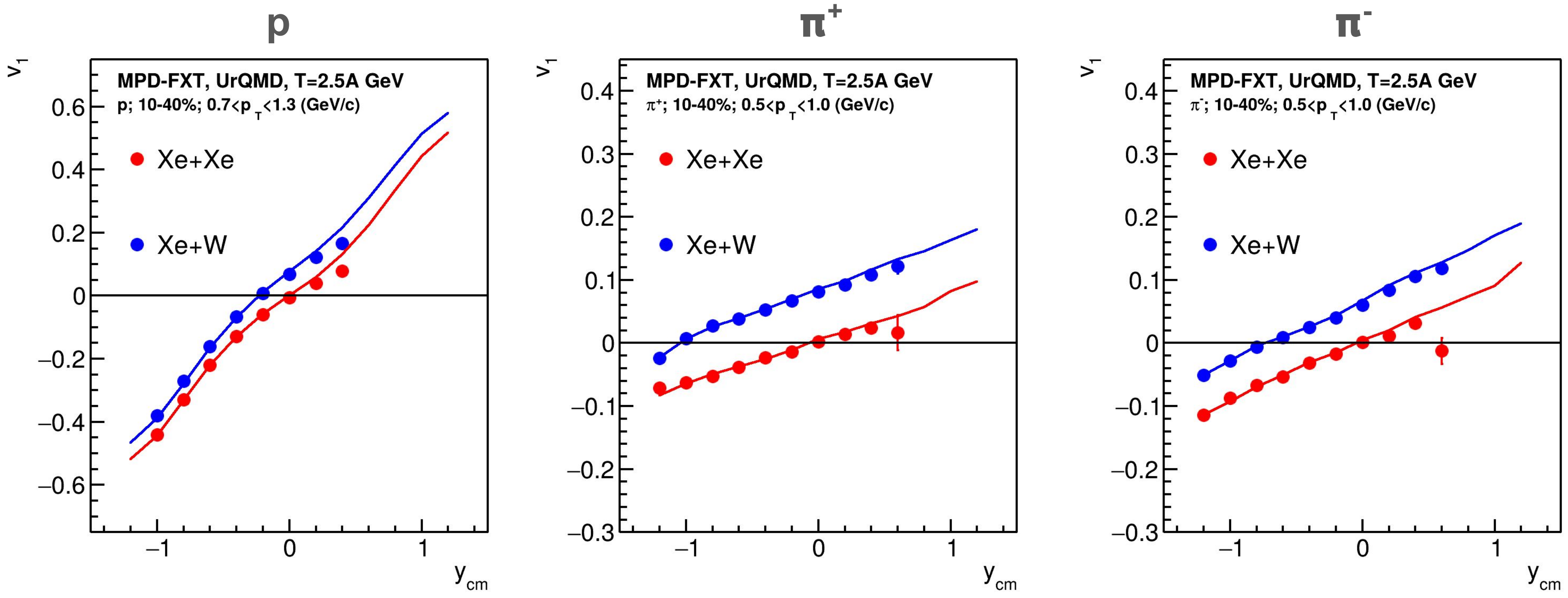
- Fit DCA$_{x,y,z}$ distributions with the gaus function for (p, $\pi^\pm$) in different p_T bins
- Use fit parameters as a base for nσ cut



2D plots show DCA$_x$ of p, $\pi^\pm$ with the corresponding 2σ cut ranges that are used for the v_n measurements

Results: $v_1(y)$

markers - reco; lines - model

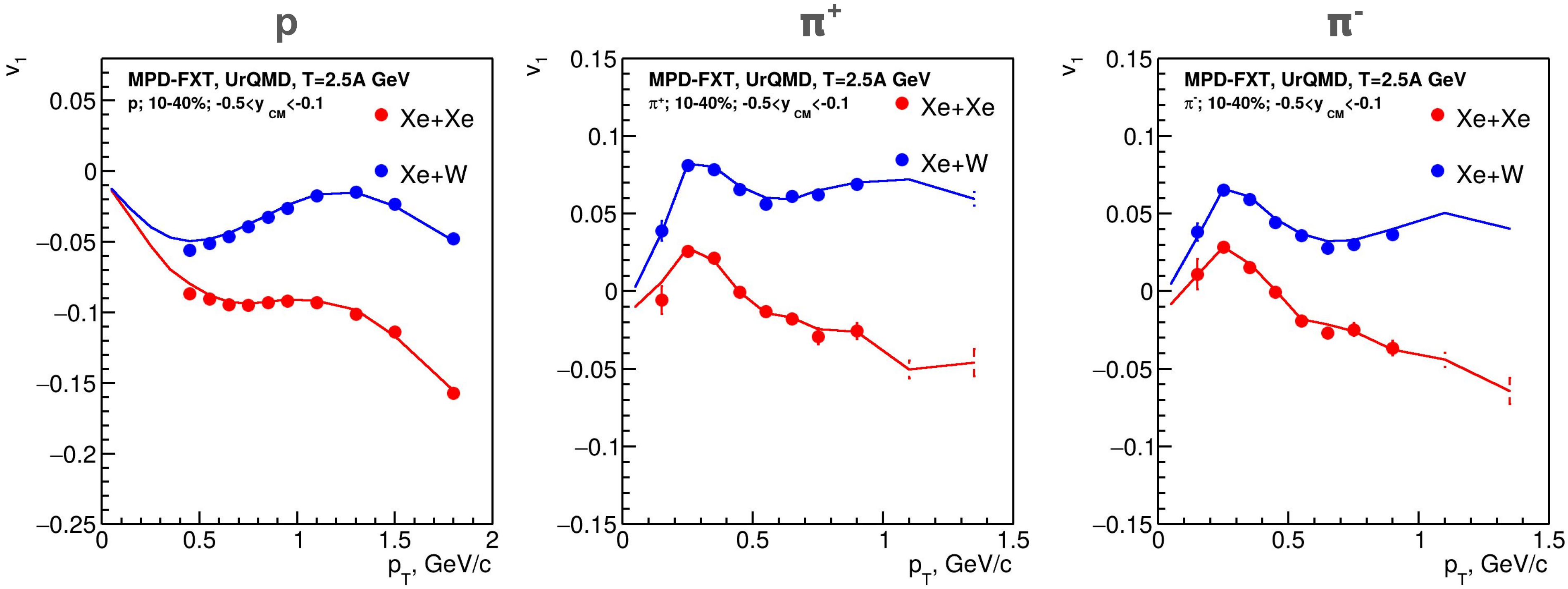


Good agreement for protons and pions for y<0.5

Clear shift in $v_1(y_{cm})$ for Xe+W - preferential deflection of the participants

Results: $v_1(p_T)$

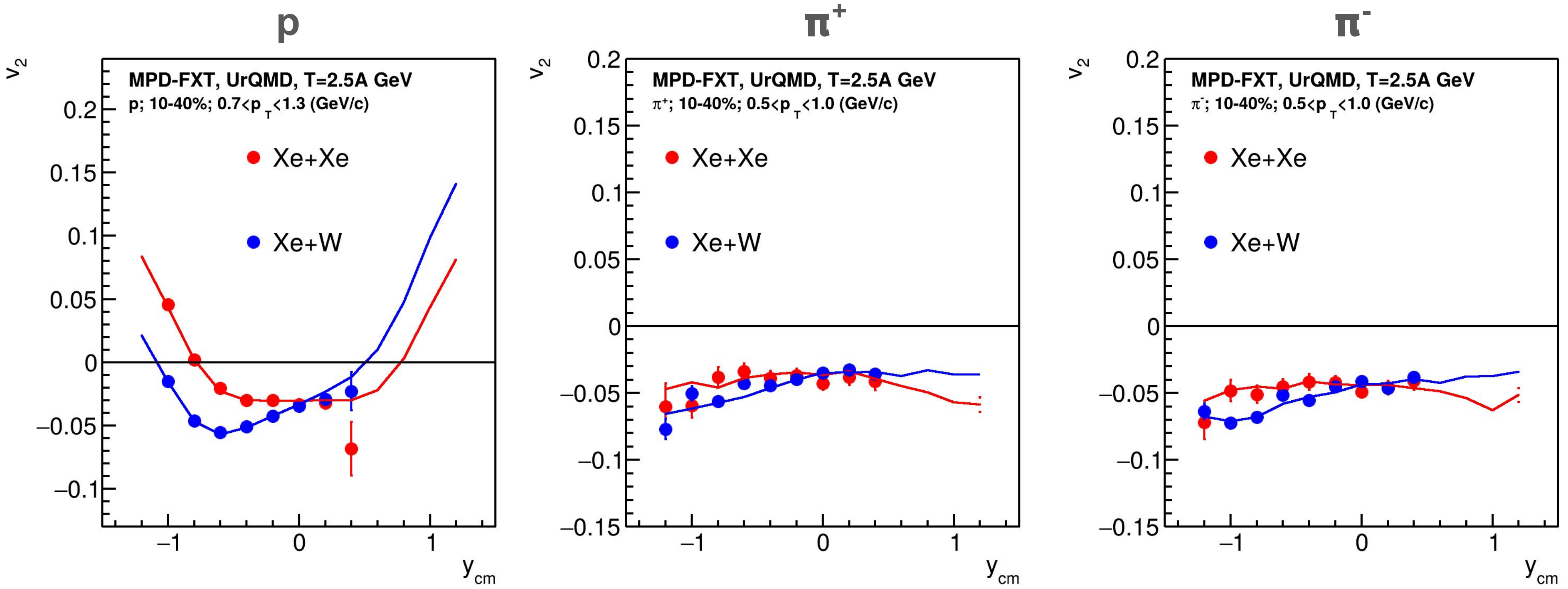
markers - reco; lines - model



Good agreement for protons and pions

Results: $v_2(y)$

markers - reco; lines - model

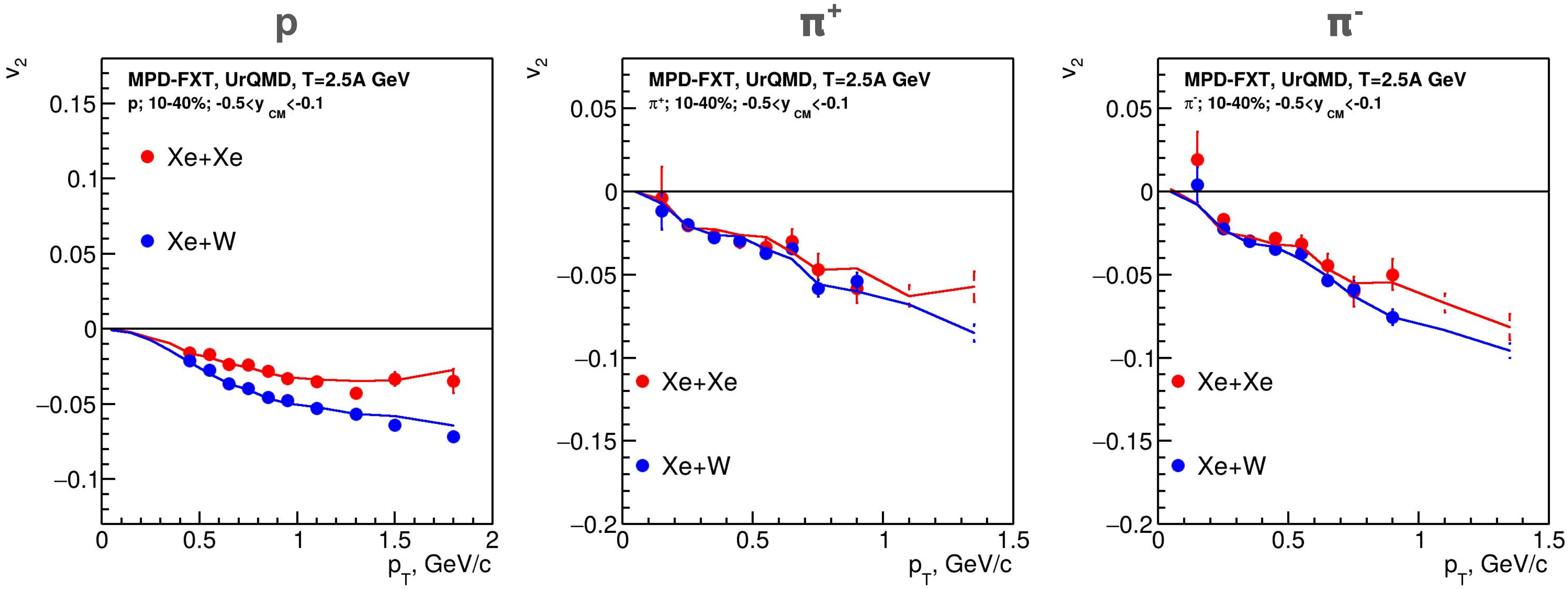


Good agreement for protons and pions for y<0.5

Asymmetric $v_2(y_{cm})$ dependence for Xe+W

Results: $v_2(p_T)$

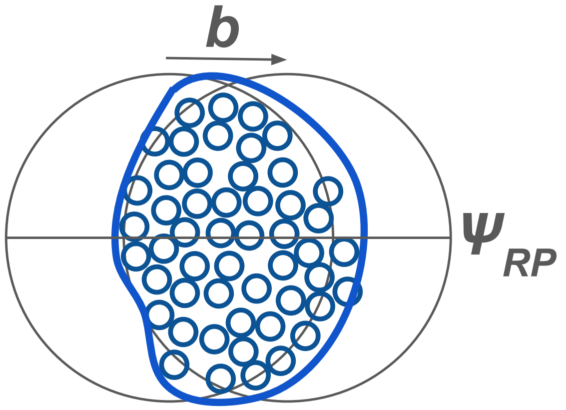
markers - reco; lines - model



Good agreement for protons and pions

Initial geometry in asymmetric collisions

Eccentricity and its fluctuations



$$\varepsilon_n = \frac{\sqrt{\langle r^n \cos(n\varphi)\rangle^2 + \langle r^n \sin(n\varphi)\rangle^2}}{\langle r^n \rangle}$$

Eccentricity fluctuations can be studied similar to the v_n fluctuations:

$\varepsilon_n\{2\} = \sqrt{\langle\varepsilon_n^2\rangle}$, $\varepsilon_n\{4\} = \sqrt[4]{|2\langle\varepsilon_n^2\rangle^2 - \langle\varepsilon_n^4\rangle|}$

$$\left|\frac{v_n\{4\}}{v_n\{2\}}\right| \simeq \left|\frac{\varepsilon_n\{4\}}{\varepsilon_n\{2\}}\right|$$

Phys.Rev.C 84 (2011) 054901
arxiv 2507.16162 (2025)

We can use MC-Glauber model to study ε_2 and its fluctuations in Xe+Xe, Xe+W, and Au+Au collisions.

Setup

Model: MC-Glauber, UrQMD

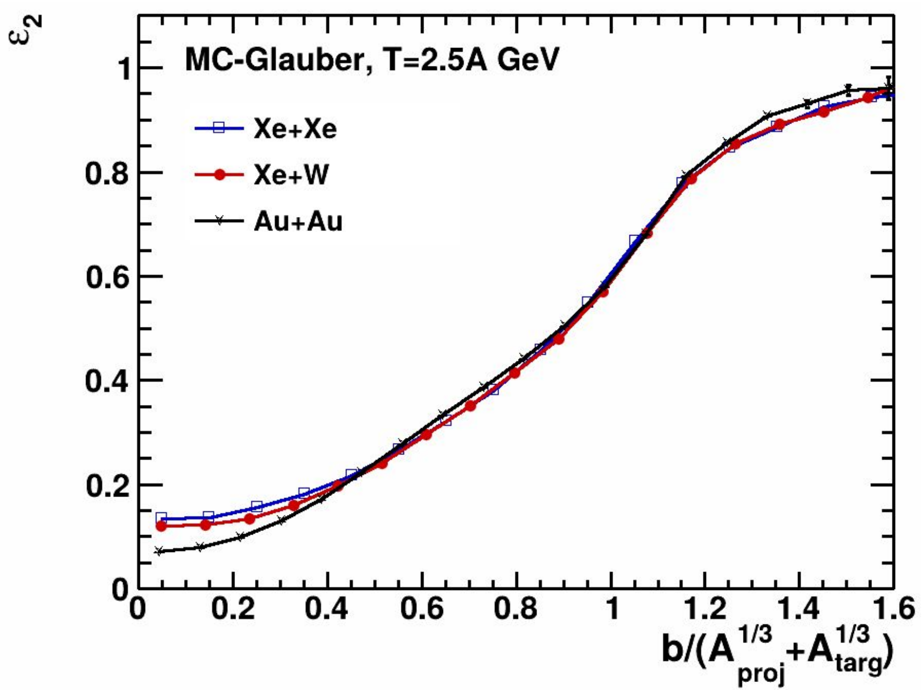
Systems: $^{124}Xe+^{124}Xe$, $^{124}Xe+^{184}W$, $^{197}Au+^{197}Au$

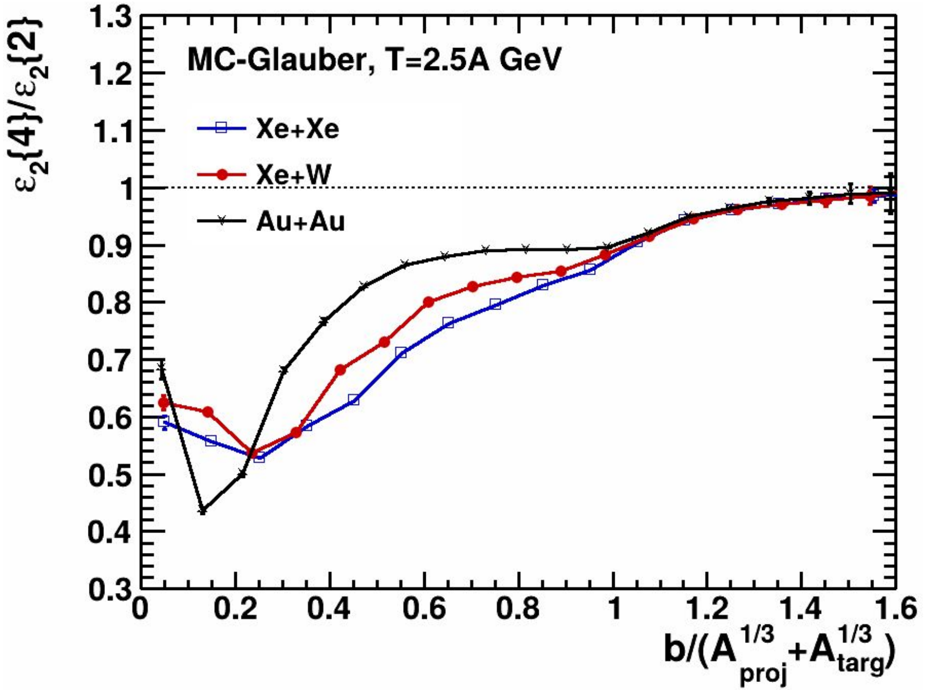
Beam energy: T=2.5A GeV ($\sqrt{s_{NN}}$=2.87 GeV)

σ_{NN}^{inel}: (Xe+Xe) 26.44 mb, (Xe+W) 26.45 mb, (Au+Au) 26.46 mb

Statistics: 100k events

ε_2: scalable geometry, but different fluctuations! ($b/A^{1/3}$)



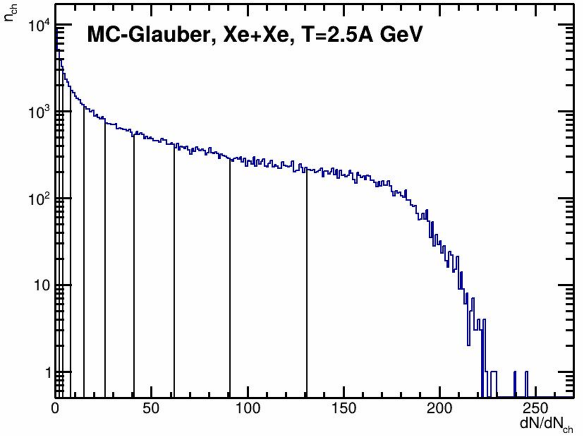


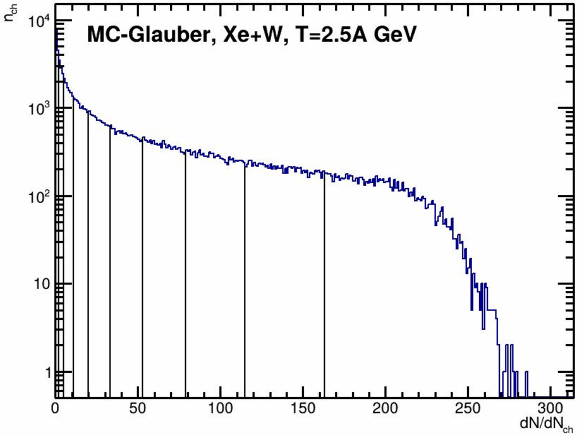
In central and mid-central collisions:

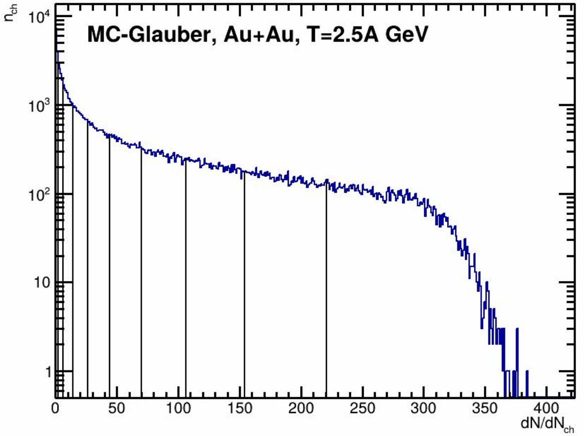
The overall geometry (ε_2) seems to scale with $A^{1/3}$, but the fluctuations ($\varepsilon_2\{4\}/\varepsilon_2\{2\}$) are different between Xe+Xe, Xe+W and Au+Au - similar trends for ε_4 as well

Going from b to N_{ch}-based centrality

Vertical lines represent centrality classes





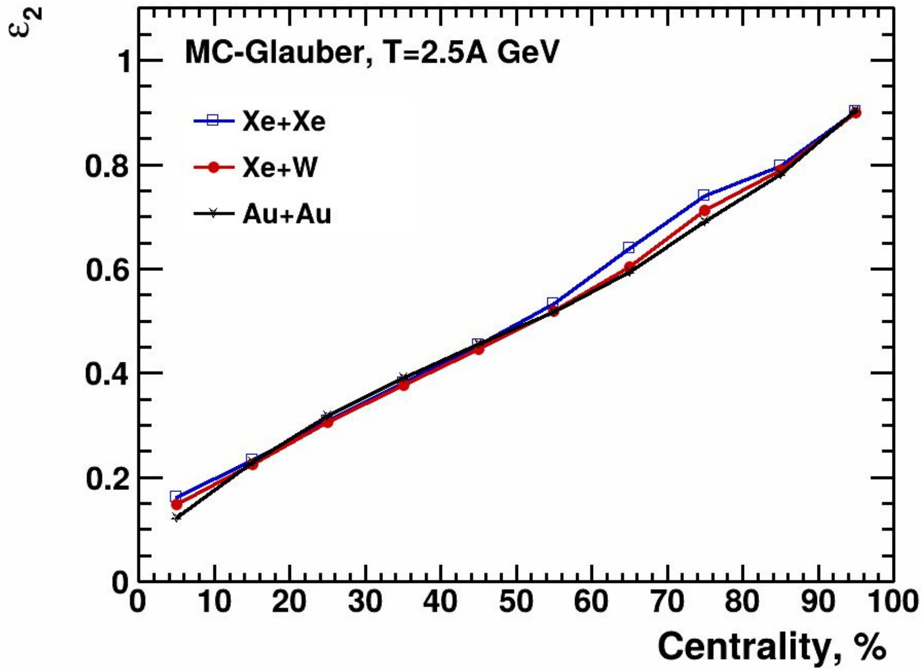


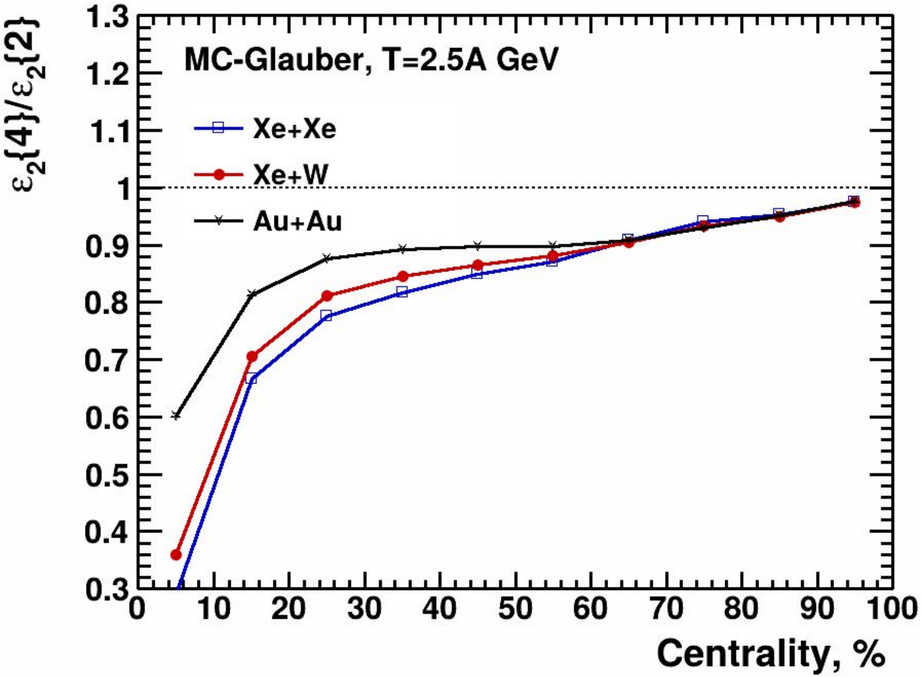
In more realistic case, collision geometry is measured using charged particle multiplicity

Multiplicity can be generated using NBD distribution and the number of ancestors N_a:

$$N_a = fN_{part} + (1\text{-}f)N_{coll},\ N_{ch} = N_a \times \mathrm{NBD}(\mu,k);\ \underline{f = 0.9,\ \mu = 0.8,\ k = 10}.$$

ε_2: scalable geometry, but different fluctuations! (centrality)



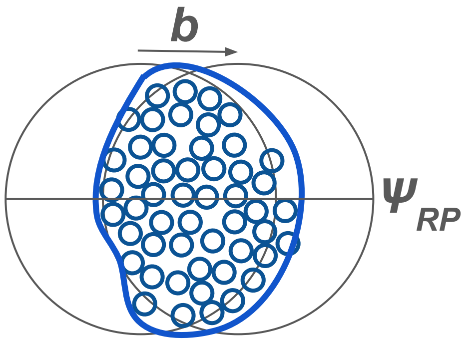


In central and mid-central collisions:

The overall geometry (ε_2) seems to scale with $A^{1/3}$, but the fluctuations ($\varepsilon_2\{4\}/\varepsilon_2\{2\}$) are different between Xe+Xe, Xe+W and Au+Au - similar trends for ε_4 as well

Eccentricity measurements in UrQMD

Phys.Rev.C 89 (2014) 6, 064908



$$\varepsilon_n = \frac{\sqrt{\langle r^n \cos(n\varphi)\rangle^2 + \langle r^n \sin(n\varphi)\rangle^2}}{\langle r^n \rangle}$$

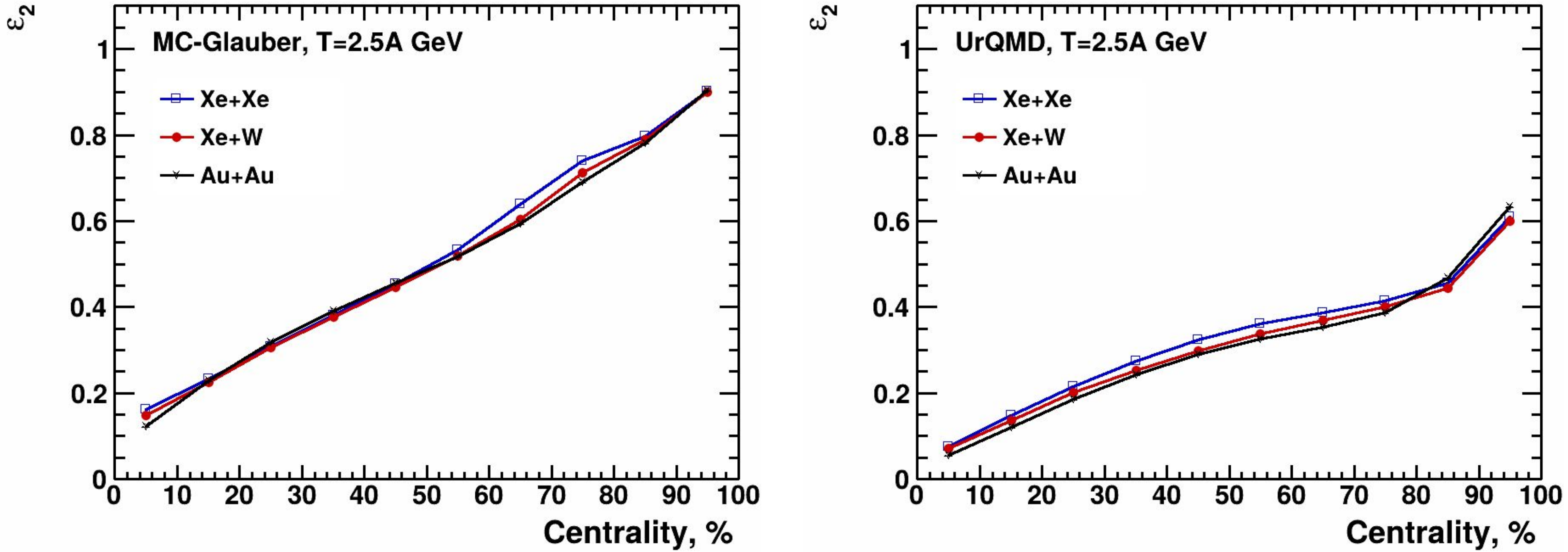
- "OSCAR1999A" format (.f20) was used
  - It stores an entire evolution of the nucleus-nucleus collision
- Calculate ε_2 and its fluctuations the same way it is done in the MC-Glauber
  - Additionally, we used only those particles, produced within t_{pass} time frame

At T = 2.5A GeV ($\sqrt{s_{NN}}$ = 2.87 GeV):

t_{pass}(Xe+Xe) = 9.38 fm/c; t_{pass}(Xe+W) = 10.32 fm/c; t_{pass}(Au+Au) = 11.32 fm/c

ε_2: MC-Glauber vs UrQMD (centrality)

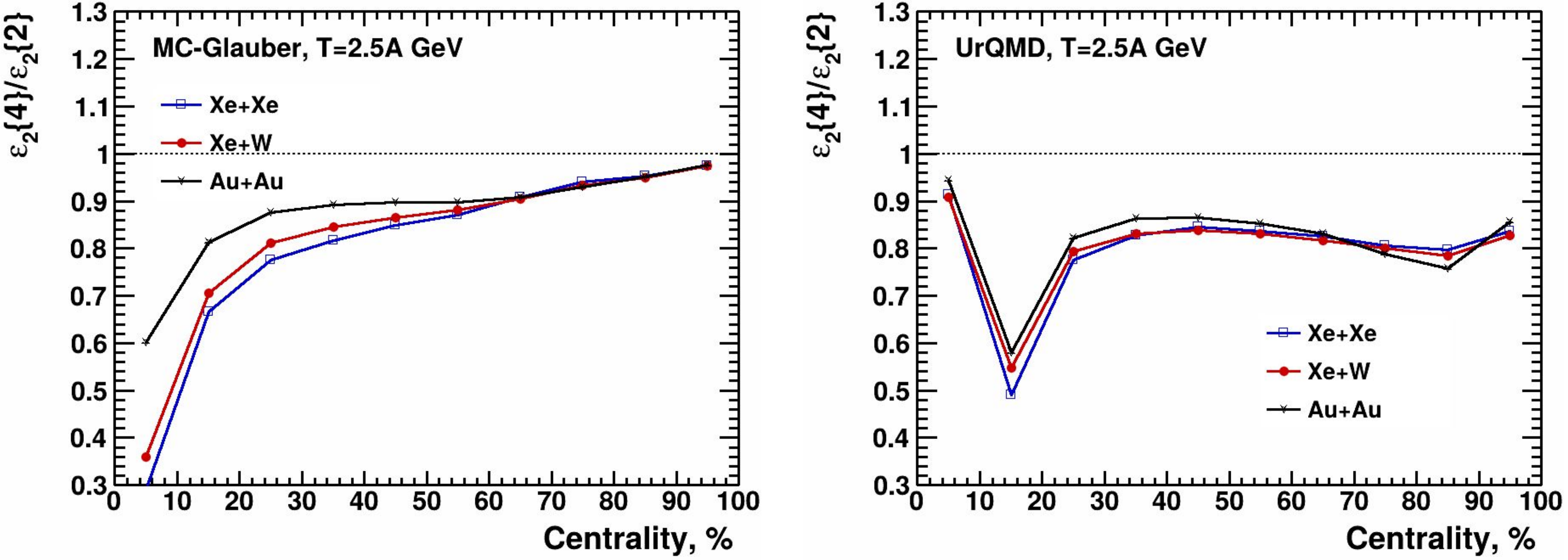
$t<t_{pass}$



Scaling works (a bit weaker though) for both MC-Glauber and UrQMD

$\varepsilon_2\{4\}/\varepsilon_2\{2\}$: MC-Glauber vs UrQMD (centrality)

$t<t_{pass}$



Possibly due to a large passing time, eccentricity fluctuations in UrQMD have enough time to “subside” and become similar(?)

Summary

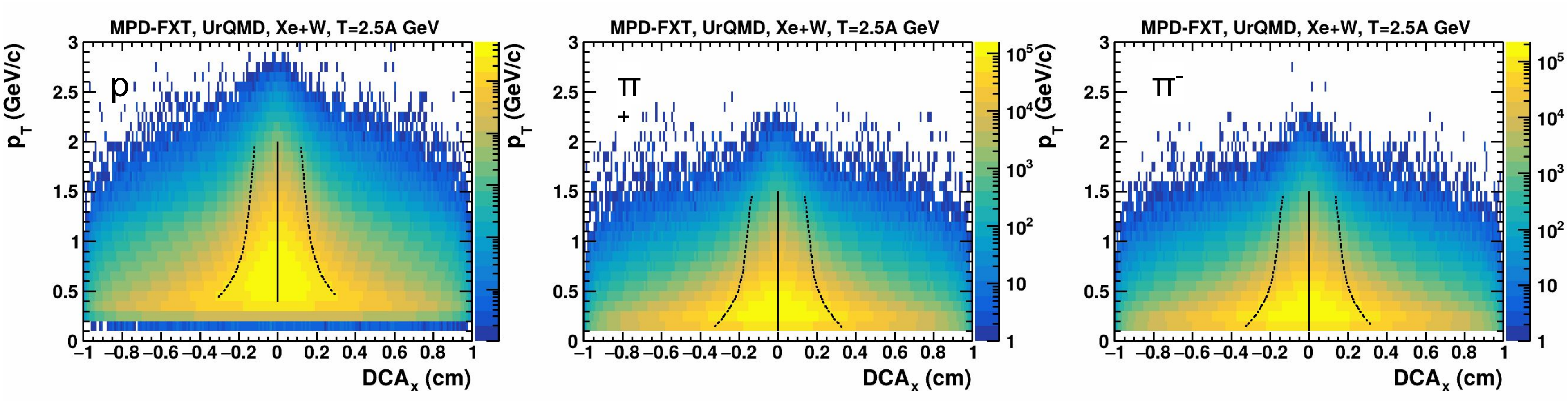
- 2σ cut for primary track selection was used this time for v_n measurements
  - Overall good agreement between “mc” and “reco”

- Quick look at the initial geometry was done for Xe+W, Xe+Xe, and Au+Au using MC-Glauber and UrQMD
  - Both models show that ε_2 scales with the size of the system
  - However, MC-Glauber predicts different ε_2 fluctuations for centrality region 0-50% while they are similar in UrQMD (accounting for t_{pass}?)

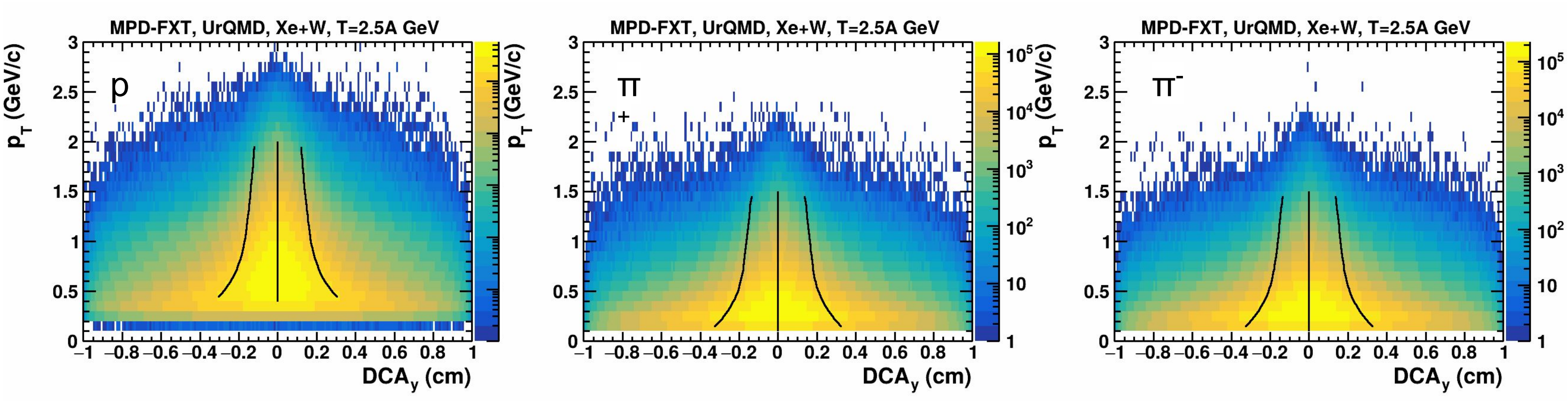
Thank you for your attention!

Backup

DCA x

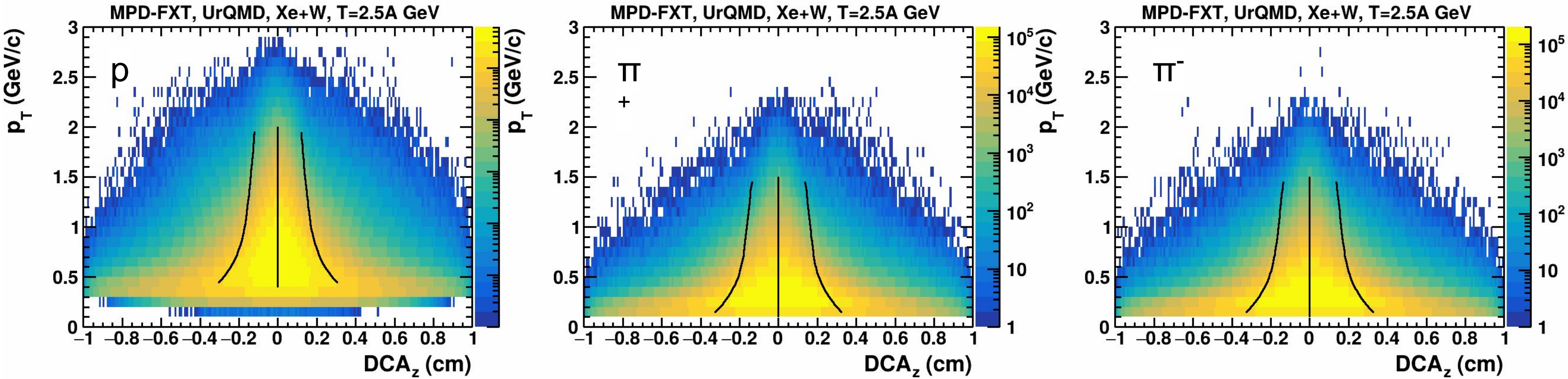


DCA y

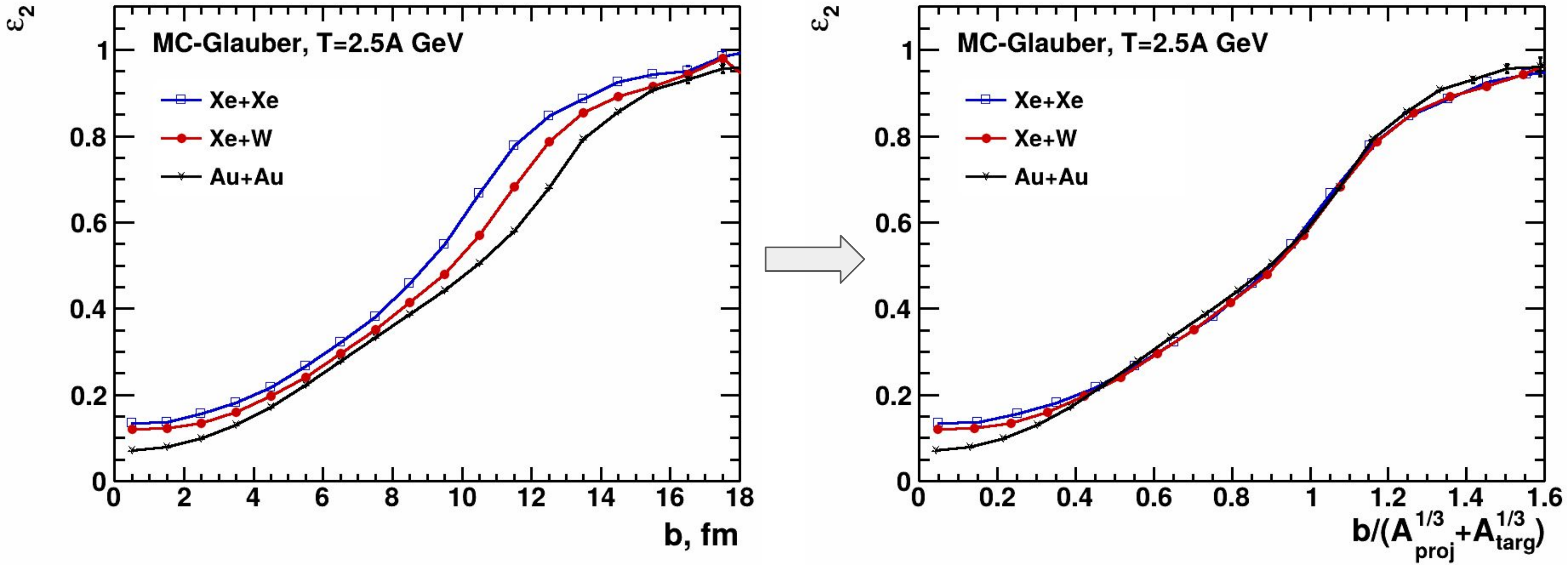


MPD-FXT, UrQMD, Xe+W, T=2.5A GeV
p
p_T (GeV/c)
DCA_y (cm)
MPD-FXT, UrQMD, Xe+W, T=2.5A GeV
π+
p_T (GeV/c)
DCA_y (cm)
MPD-FXT, UrQMD, Xe+W, T=2.5A GeV
π-
p_T (GeV/c)
DCA_y (cm)

DCA z



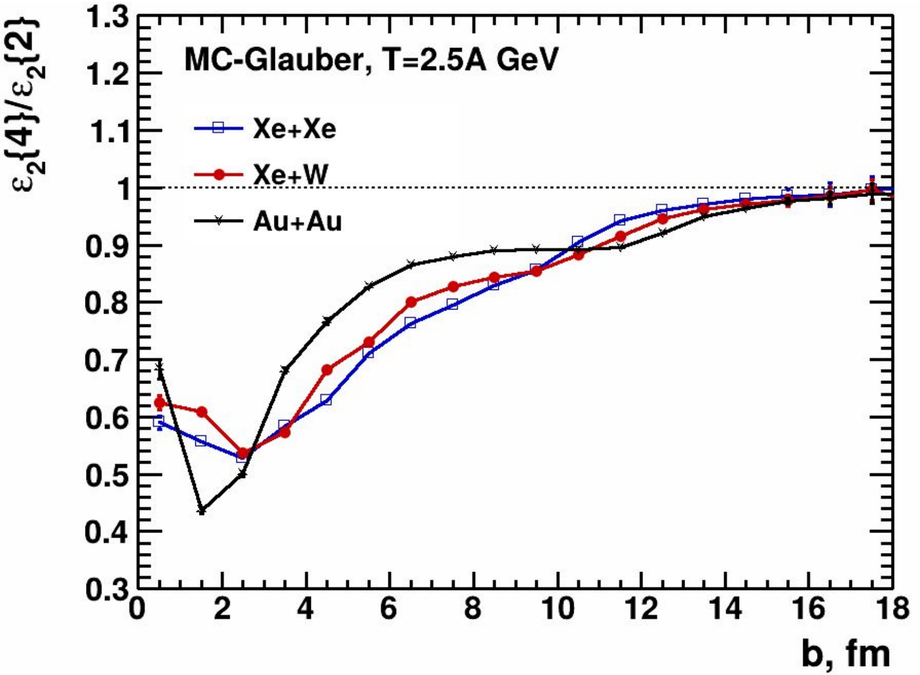
Scale with $A^{1/3}$ for impact parameter: ε_2

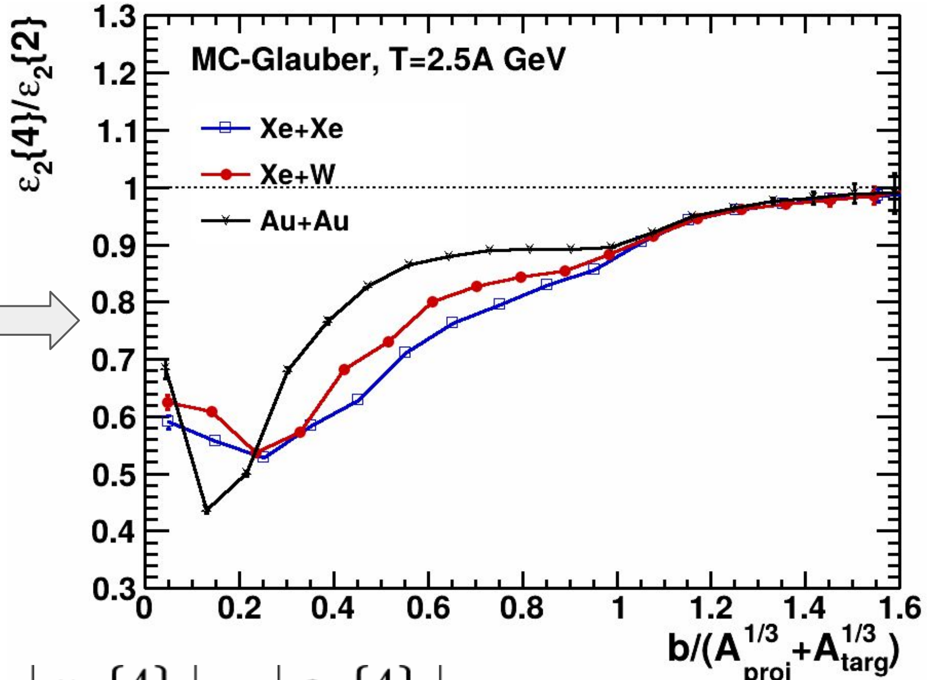


$A_{Xe} = 124$, $A_W = 184$, $A_{Au} = 197$

ε_2 scales rather well with $A^{1/3}$ of the nuclei (small differences with Au+Au)

$\varepsilon_2\{4\}/\varepsilon_2\{2\}$ check (fluctuations): scaling with $A^{1/3}$





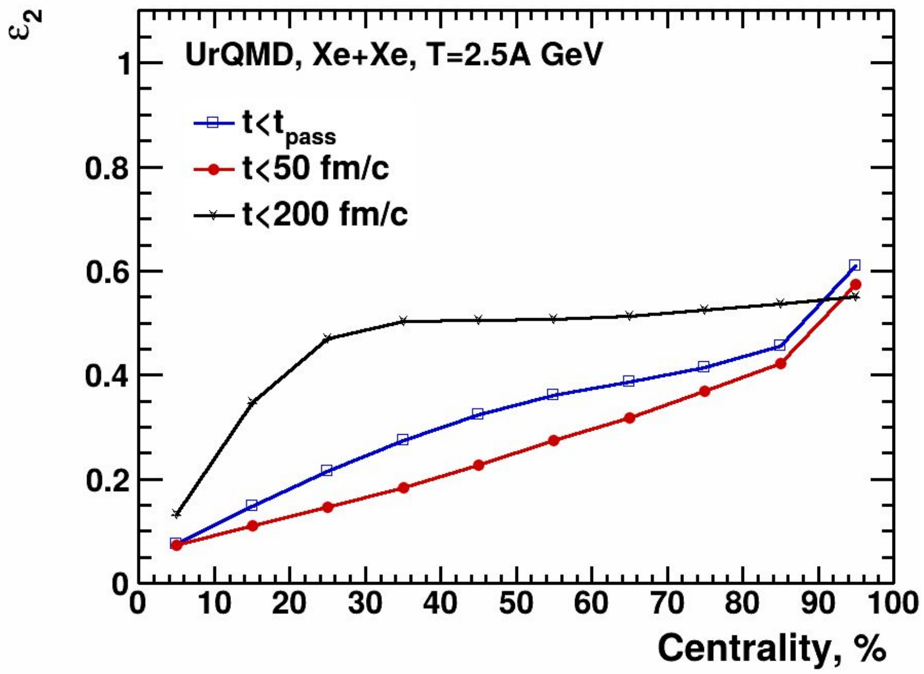
$\varepsilon_n\{2\} = \sqrt{\langle\varepsilon_n^2\rangle}$, $\varepsilon_n\{4\} = \sqrt[4]{|2\langle\varepsilon_n^2\rangle^2 - \langle\varepsilon_n^4\rangle|}$

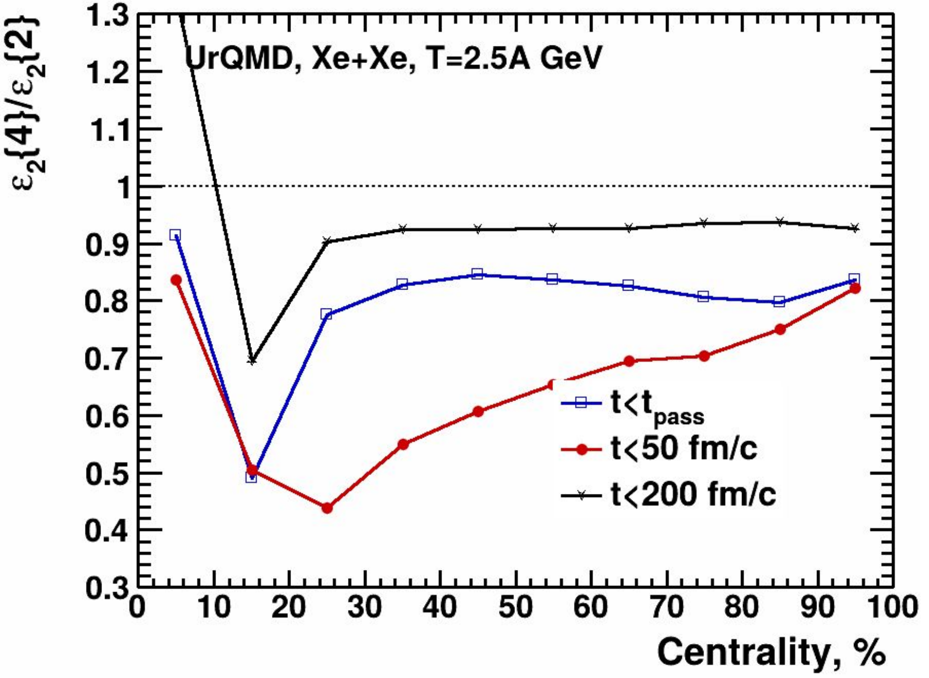
$$\left|\frac{v_n\{4\}}{v_n\{2\}}\right| \simeq \left|\frac{\varepsilon_n\{4\}}{\varepsilon_n\{2\}}\right|$$

Phys.Rev.C 84 (2011) 054901
arxiv (2507.16162)

Difference in central and mid-central, same in the periphery

ε_2 at different time cuts (centrality)





Both eccentricity and fluctuations highly depend on time cut.