How to discern between initial-state-driven (CGC-EFT) and final-state-driven (Flow) azimuthal anisotropy

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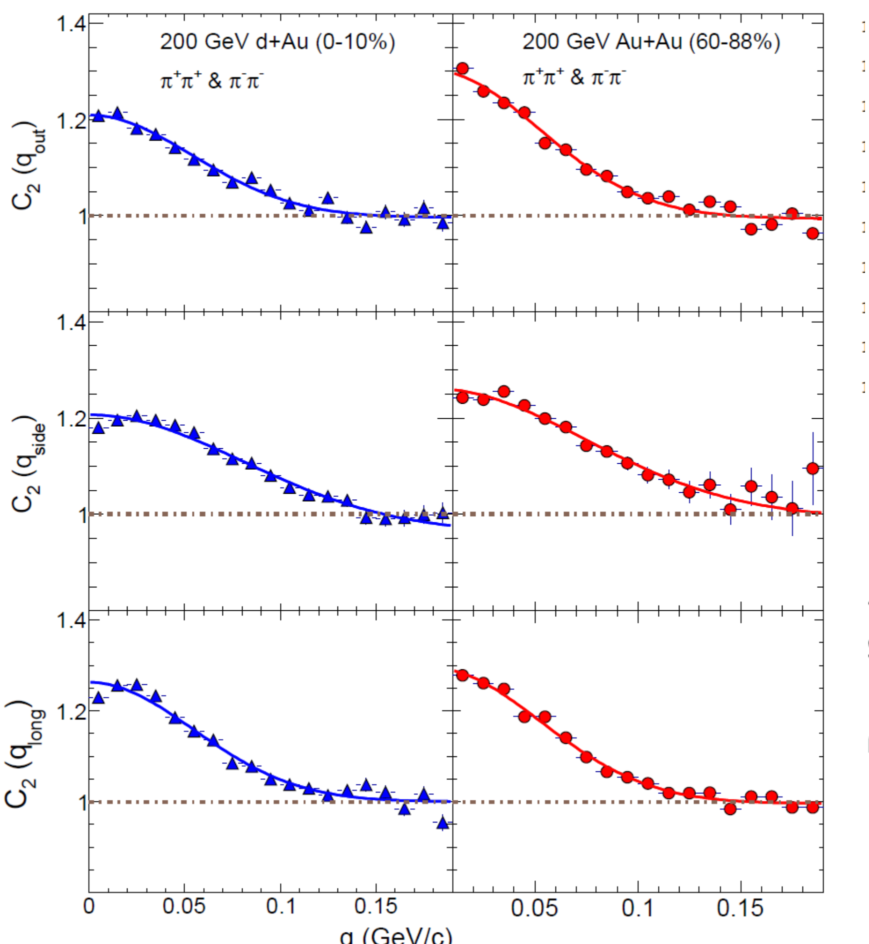
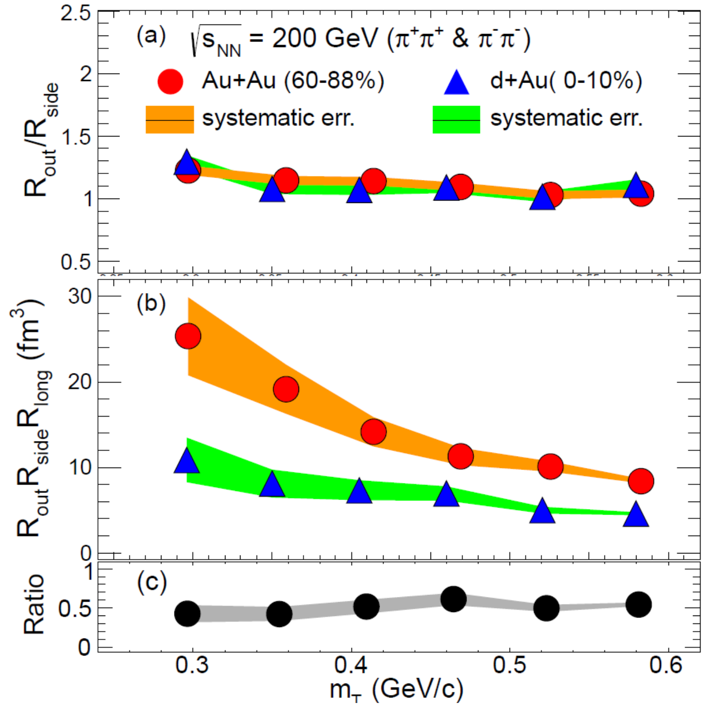
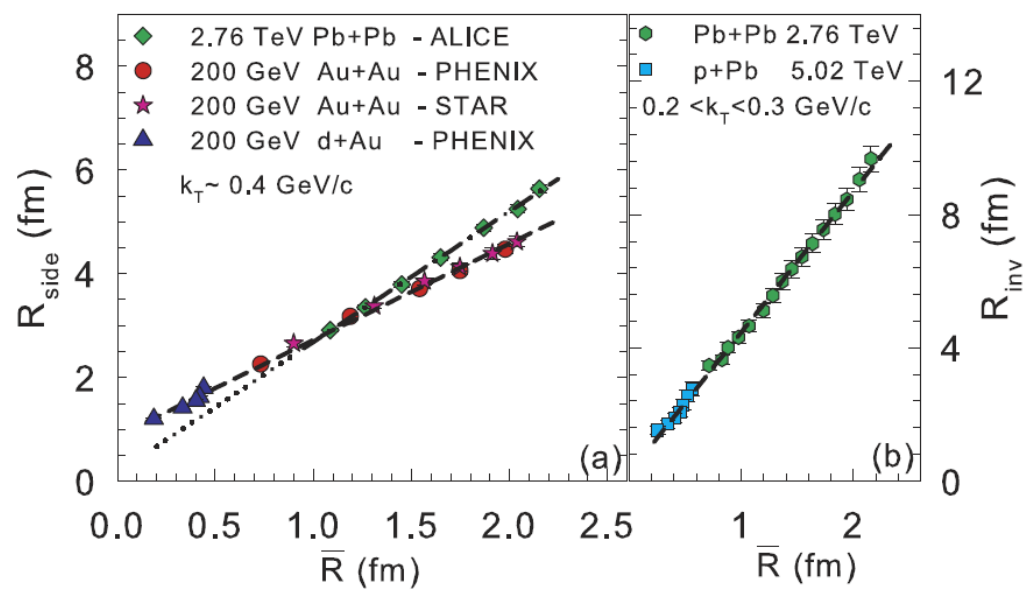
Response to HBT request

Comparison of the space-time extent of the emission source in d+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

PHENIX Collaboration Author List (Brant will insert later)
(Dated: April 12, 2014)







How to discern between initial-state-driven (CGC-EFT) and final-state-driven (Flow) azimuthal anisotropy

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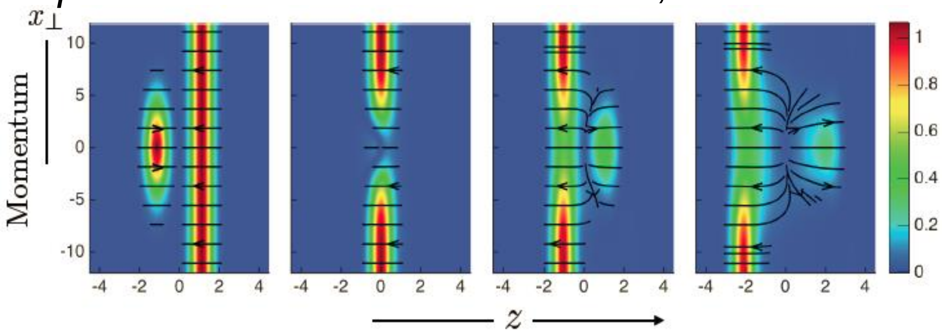
I. Backdrop to the strategy
II. Anatomy of a few key variables
III. Results focusing on the discerning role of:
- ✓ N_{chg} , ε_n *and* $\frac{\eta}{s}$
- ✓ *Fluctuations*
- ✓ *Anti/Correlations*

IV. Summary & Conclusions

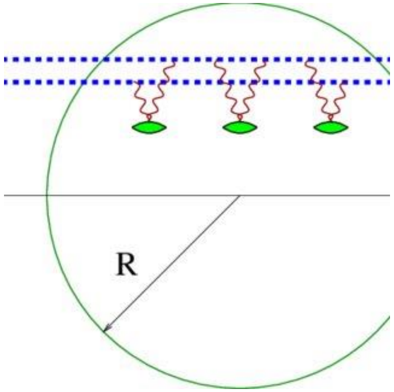
Backdrop – How to discern between models

p+A collision **Flow** *P. Chesler,* **arXiv:1601.01583**



CGC-EFT

arXiv:1807.00825



Hydrodynamic expansion dynamics works for sizes as small as RT ~ 1

Flow is acoustic

$$v_n = \varepsilon_n e^{-n\left[n\left(\frac{4}{3}\frac{\eta}{s}+\frac{\xi}{s}\right)+\kappa p_T^2\right]\frac{1}{RT}}, \; RT \propto \langle N_{chg}\rangle^{1/3}$$

Specific respective influence from:

$$\varepsilon_n, \delta\varepsilon_n, C_r(\varepsilon_n, \varepsilon_m), \; n^2, \; \left(\frac{4}{3}\frac{\eta}{s}+\frac{\xi}{s}\right), \; p_T^2, \; \langle N_{chg}\rangle^{1/3}$$

ε_n & its fluctuations — correlations — *visc. attenu.*

Eikonal-like scattering of quarks off of a gluon dense nuclear target

Controlling influence from:

$$Q_{s,T} << p_T^{max}, \; Q_{s,p}(B_p)$$

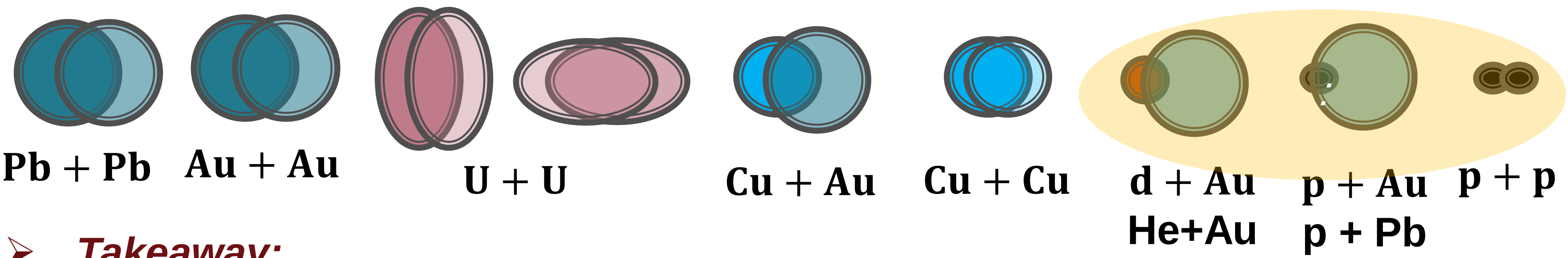
$$v_{2n}\{2\} \propto N_{chg}^{0}, \; v_{2n+1}\{2\} \propto N_{chg}^{1/2}, \; \delta(v_n), \; C_r(n,m)$$

$$\varepsilon_n\left(+\delta\varepsilon_n + C_r(\varepsilon_n, \varepsilon_m)\right), \; n^2, \; \left(\frac{4}{3}\frac{\eta}{s}+\frac{\xi}{s}\right), \; p_T^2, \; \langle N_{chg}\rangle^{1/3}$$

- ***There are several specific contrasting dependencies which can be leveraged to discern between these final- and initial-state models***

Commentary -1

- **The azimuthal anisotropy in systems spanning the broadest range of $\sqrt{s_{NN}}$, collision-system sizes, shapes and asymmetries should be employed for any meaningful distinction between Flow and CGC-EFT models.**
  - ✓ **arXiv:1901.08155, arXiv:1804.04618, arXiv:1802.06595 (recent examples)**



- ***Takeaway:***
  - ***The dimensionless size*** $RT \propto \langle N_{chg} \rangle^{1/3}$***, is the size metric and*** *small systems* ***are created irrespective of colliding species – not just in p+A, d+A, etc.***

$$\left(\frac{dN_{chg}}{d\eta}\right)_{|\eta|=0.5} = \mathrm{N}_{\mathrm{qpp}}\left[b_{AA} + m_{AA}\ \ln\left(\sqrt{s_{NN}}\right)\right]^3$$

$$b_{AA} = 0.5303 \pm 0.008, \quad m_{AA} = 0.1131 \pm 0.002$$

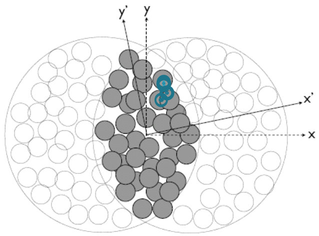
Universe 4 (2018) no.1, 22 **arXiv:1601.06001**

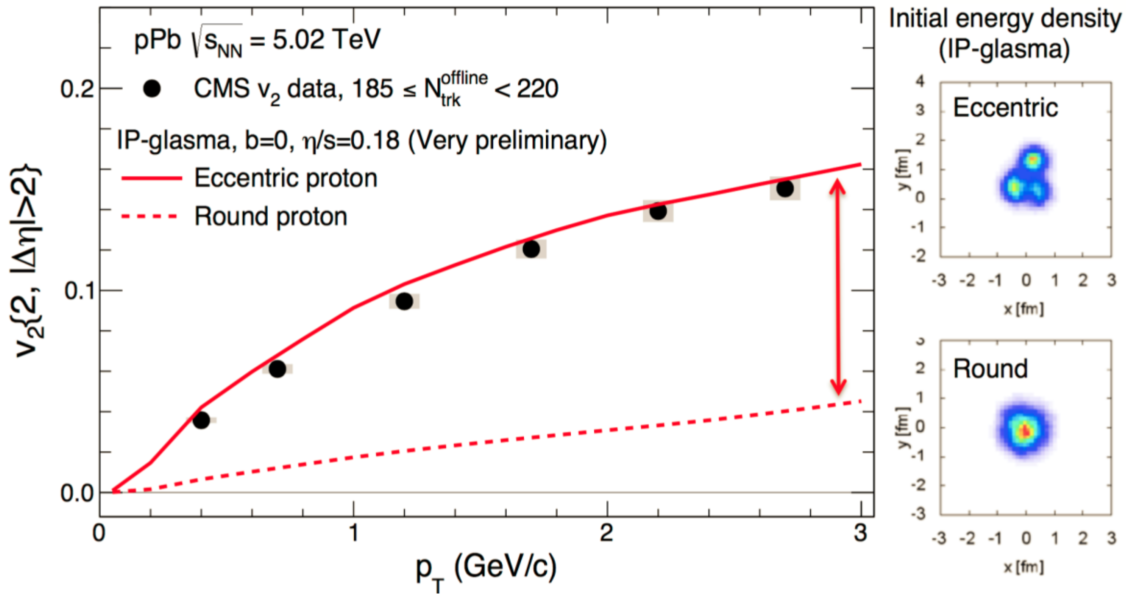
There are many ways to vary dimensionless size, shape, viscous attenuation, fluctuations, v_n-correlations., etc.

Eccentricity

Bjoern Schenke SQM16

MC-quarkGlauber





A quarkGlauber model is used to characterize the nucleonic sub-structure across collision-systems

Valence quarks substructure

- *q-q cross section adjusted to reproduce n-n inelastic cross section*
- *quarks in each nucleon selected from charge distribution*
- *q-q profile constrained with elastic scattering measurements rms radius*

$$\varepsilon_n = \sqrt{\left\langle |\mathcal{E}_n|^2 \right\rangle}, \quad \varepsilon^{mc}_{4,(2,2)} = \sqrt{\langle \epsilon_2^4 \rangle},$$

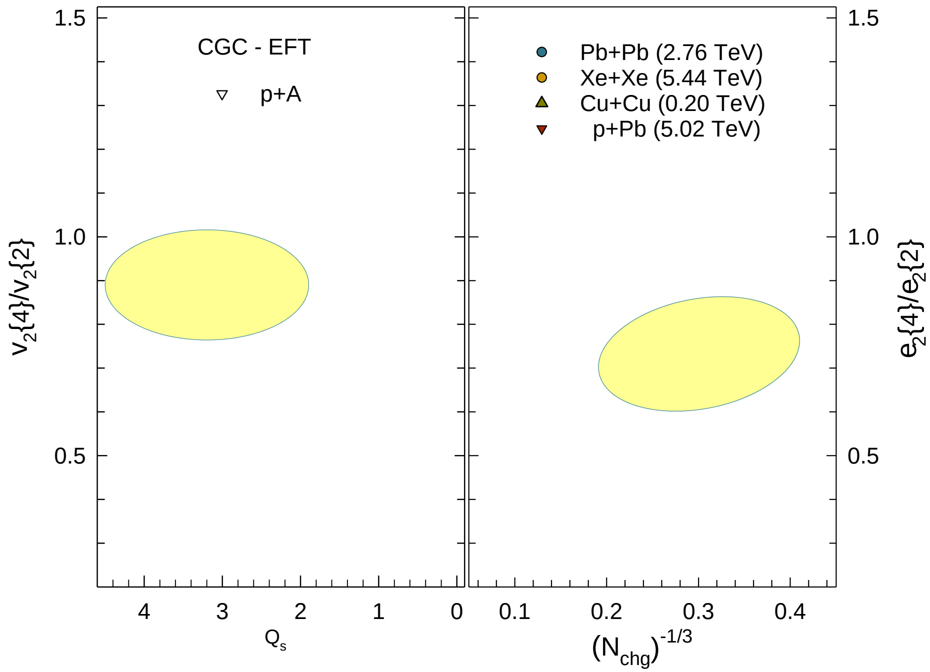
$$\varepsilon^{mc}_{5,(2,3)} = \sqrt{\langle \epsilon_2^2 \epsilon_3^2 \rangle}, \quad \varepsilon^{mc}_{6,(3,3)} = \sqrt{\langle \epsilon_3^4 \rangle},$$

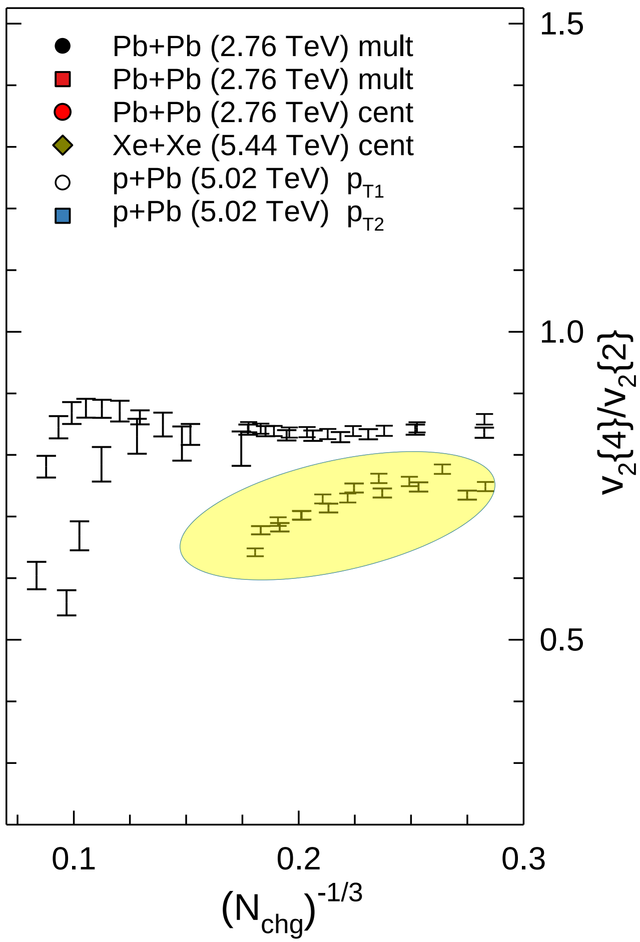
$$\varepsilon^{mc}_{6,(2,2,2)} = \sqrt{\langle \epsilon_2^6 \rangle}, \quad \varepsilon^{mc}_{7,(2,2,3)} = \sqrt{\langle \epsilon_2^4 \epsilon_3^2 \rangle}.$$

➢ ***Geometric consistency across collision-systems***
 ✓ ***Important constraint for ε_n-fluctuations***

Flow Fluctuations are discerning

- **Model discerning character of flow fluctuations**



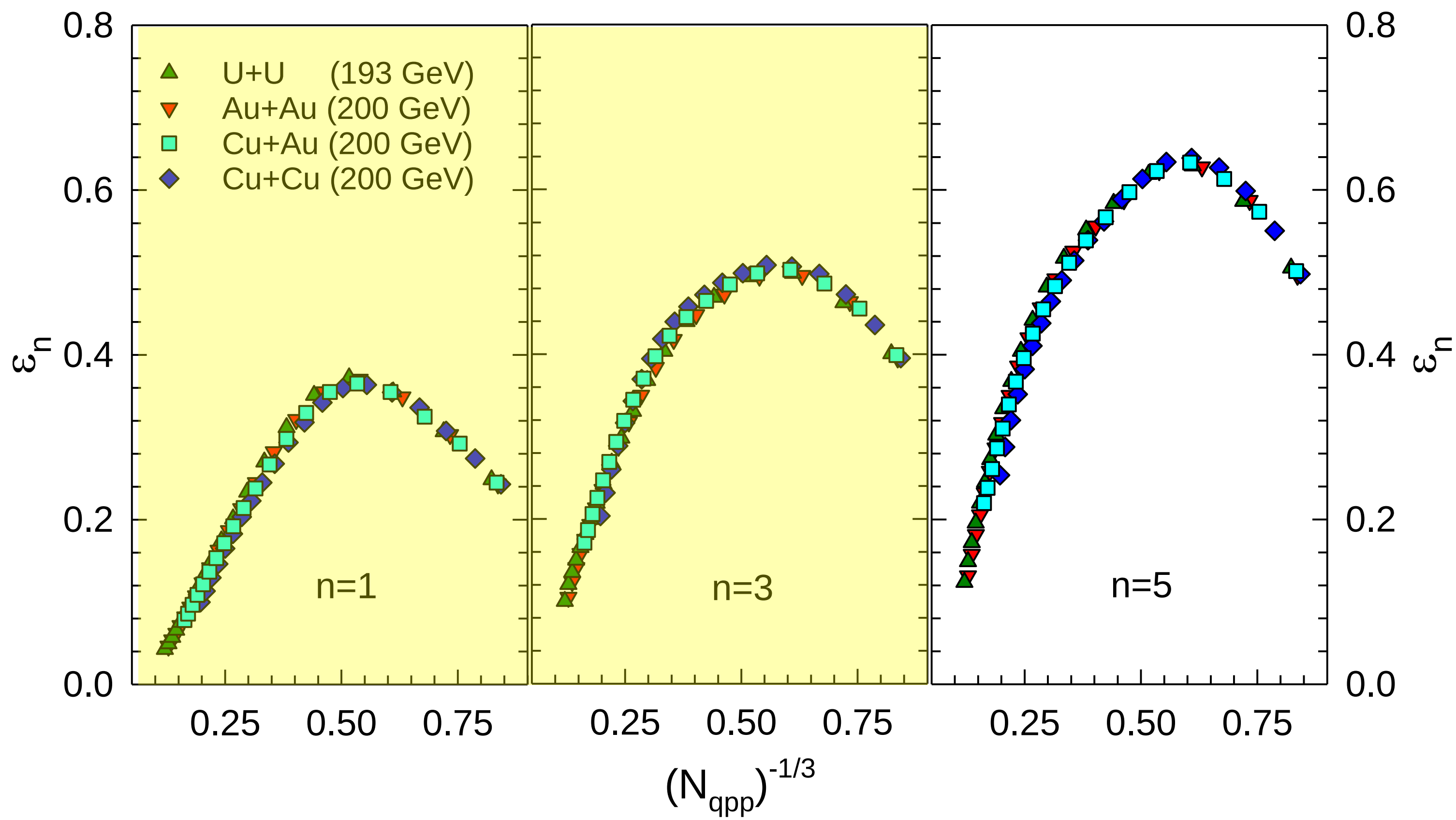


Eccentricity fluctuations dominate flow fluctuations

- ✓ ***A characteristic model-dependent difference in the N_{chg} dependence of fluctuations is expected***

These dependencies pose a challenge to CGC-EFT models

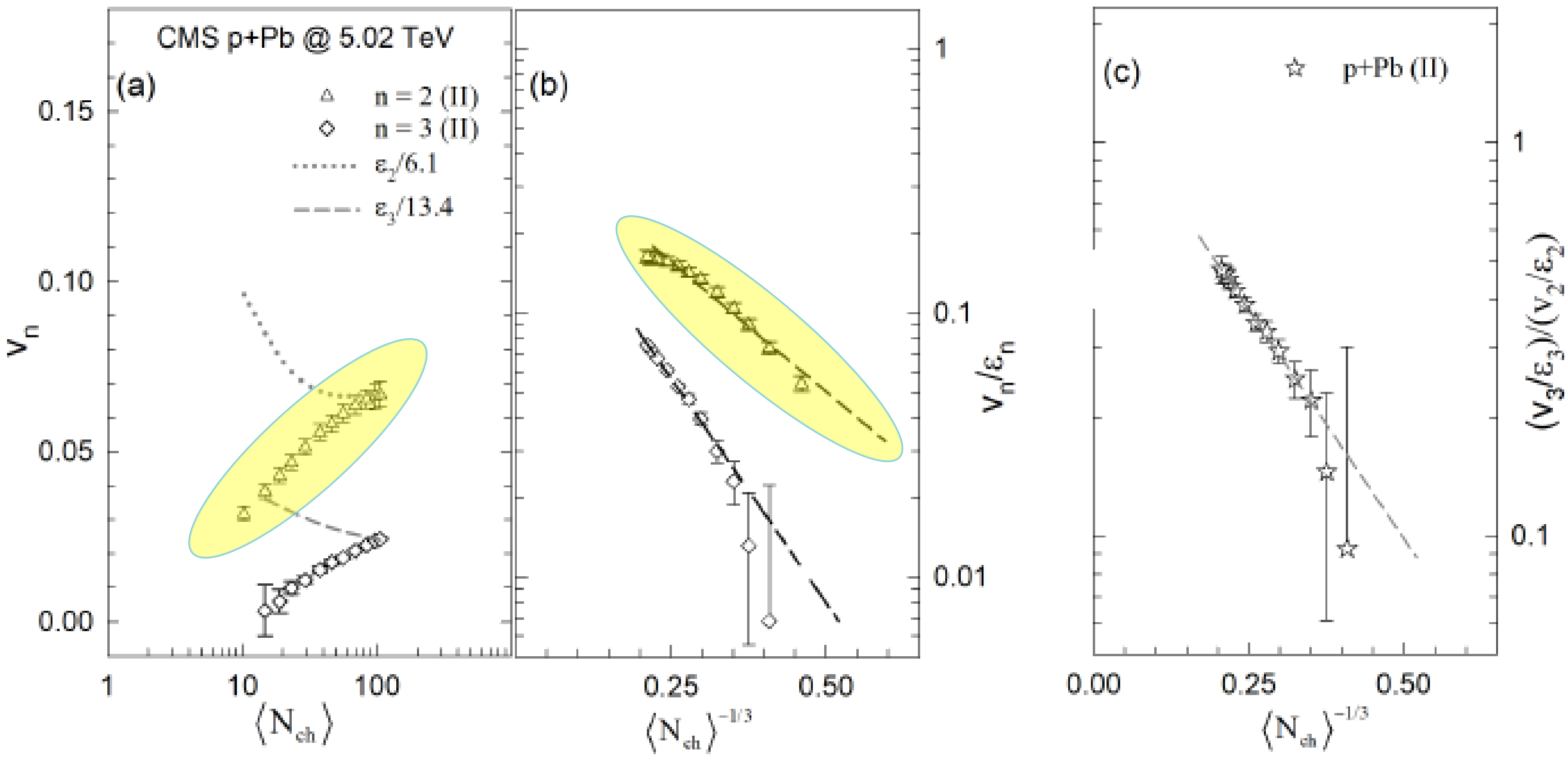
Collision-system dependent shape response - ε_n



- ***Odd eccentricity moments are fluctuations driven***
  - ✓ ***Little, if any, system dependence for A+A(B) collisions for similar dimensionless size***

Acoustic Scaling – System size

Phys. Rev. C **98**, 031901(R), 2018



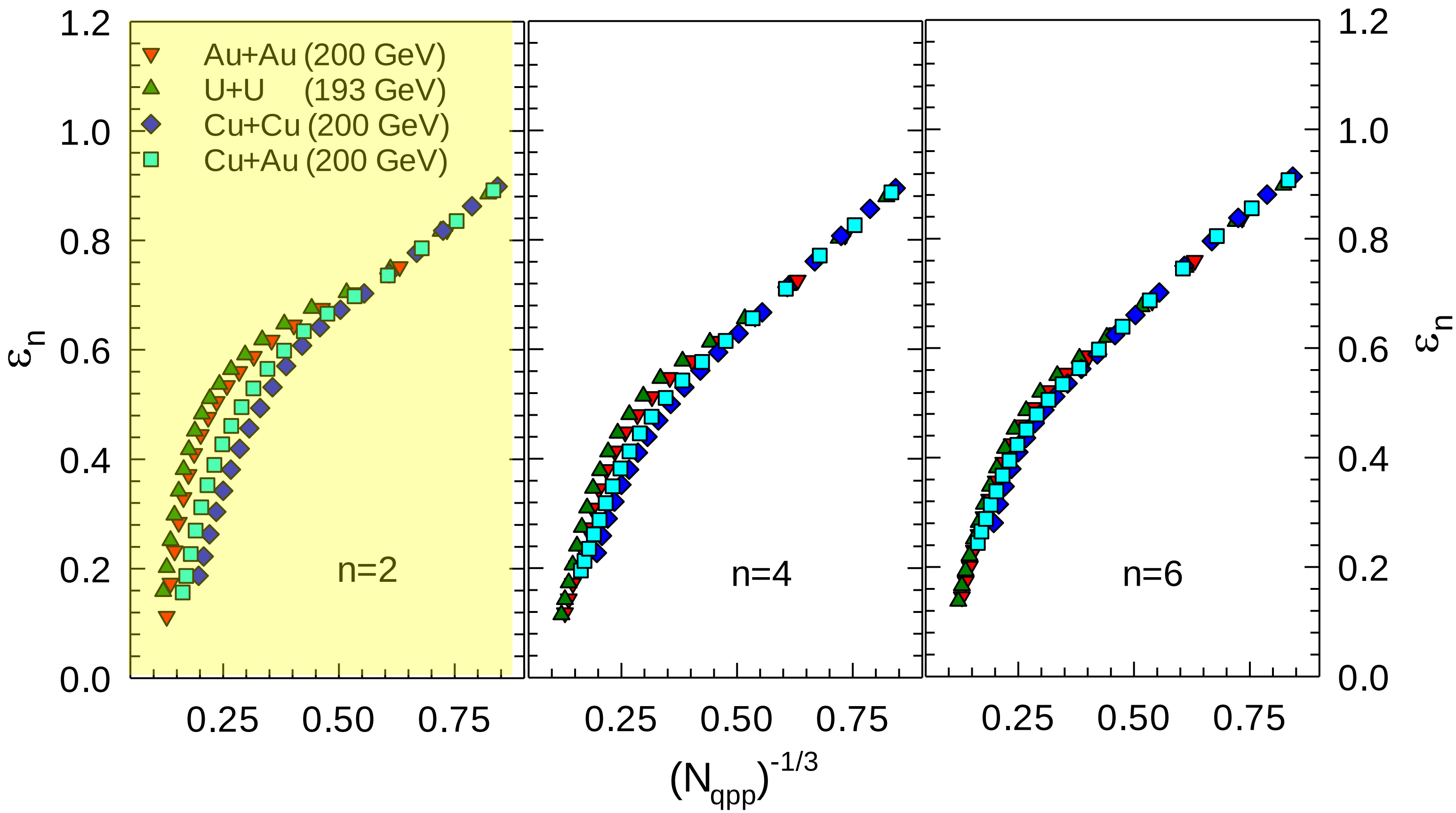
- **Eccentricity change <u>alone</u> is not sufficient**
  - ✓ **Same pattern as in peripheral Pb+Pb**

✓ **Characteristic 1/(RT) viscous damping similar to that for p+Pb collisions of similar "size"**

✓ **Viscous damping supersedes the influence of eccentricity**

  - ✓ ***Important constraint for η/s & ζ/s***

Collision-system dependent shape response - ε_n

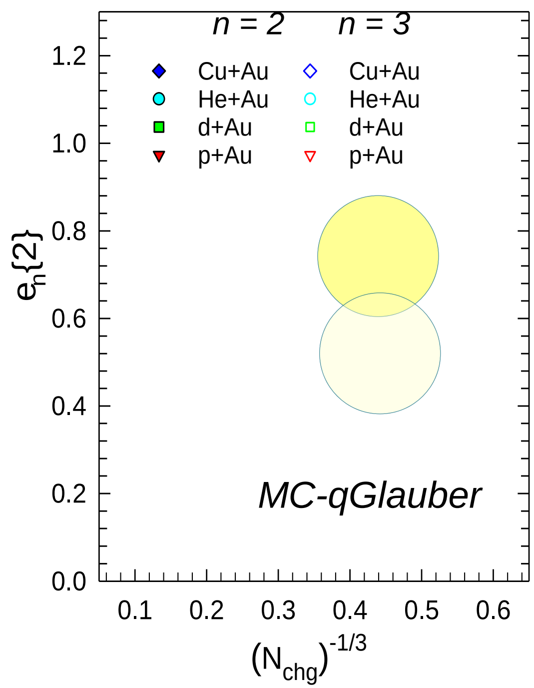


- ***Even eccentricity moments are shape driven***
  - ✓ ***Sizeable system dependence for A+A(B) collisions in central & mid-central collisions***
  - ✓ ***System independence in peripheral collisions***

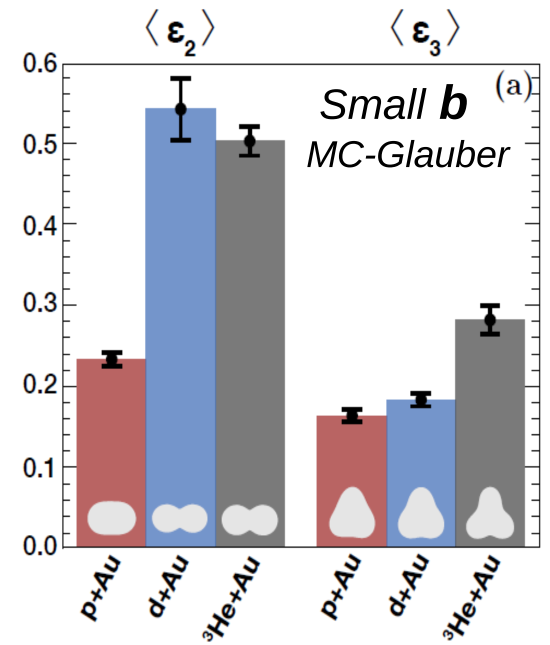
Shape response

- **Similar eccentricity patterns observed for small and large collision-systems for the same dimensionless size.**
  - ✓ **Small shape (ε_2 and ε_3) dependence on collision-system for similar dimensionless size.**

- ✓ **Sub-nucleonic degrees of freedom are especially important for small collision-systems**



arXiv:1805.02973

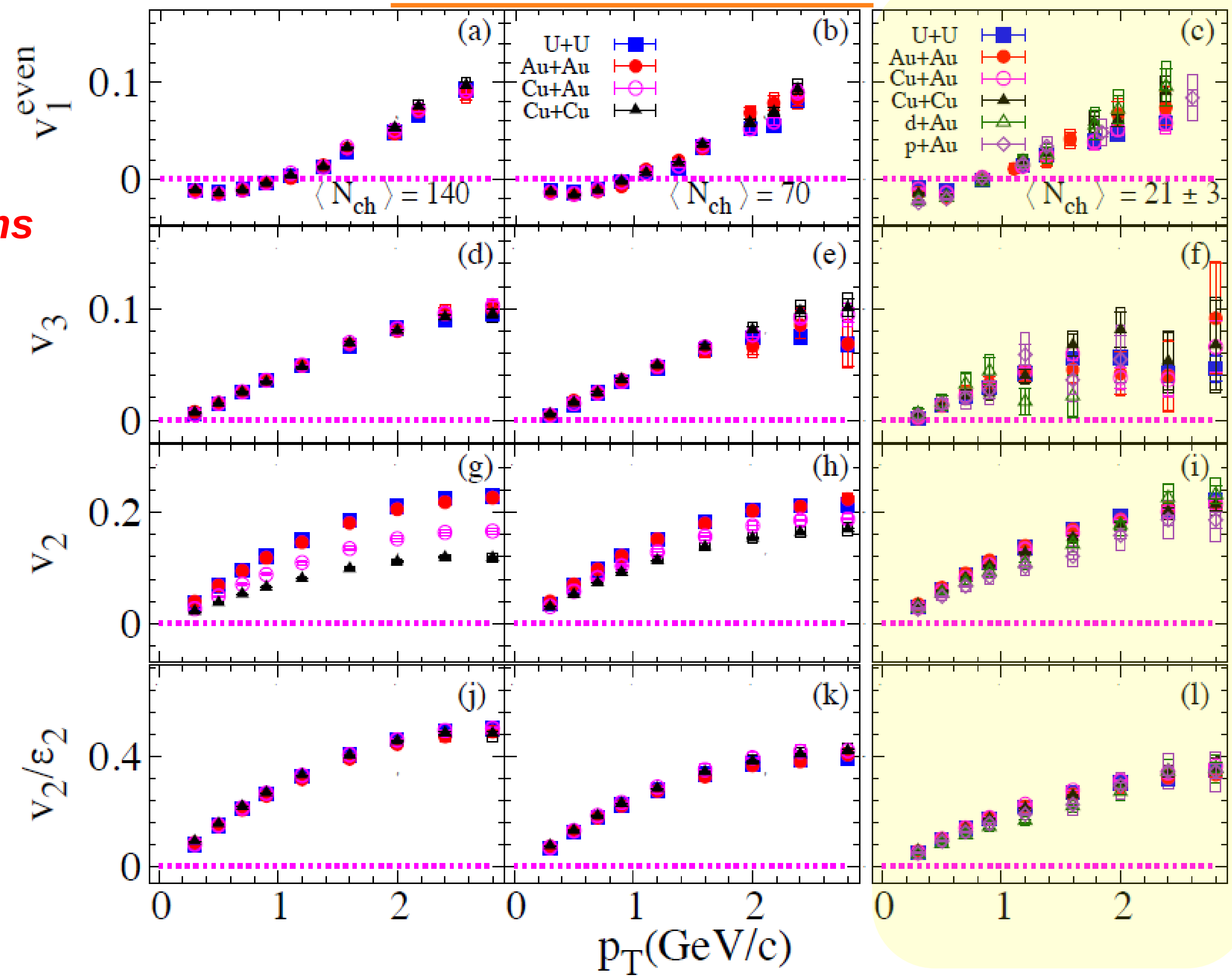


Circular, elliptical & triangular droplets ??

- **Key consequence**
- ✓ **Similar $v_{2,3}$ patterns expected for small and large collision-systems, for the same dimensionless size $RT \propto \langle N_{chg} \rangle^{1/3}$.**
- ✓ **Little difference between collision-systems**

Shape Response

STAR - arXiv:1901.08155



Comparison of collision-systems at ~ similar $\sqrt{s_{NN}}$ and $\langle N_{ch} \rangle$

✓ *Collision-system dependence of $v_n(p_T)$ for fixed values of $\langle N_{ch} \rangle$*

Challenge to CGC-EFT models?

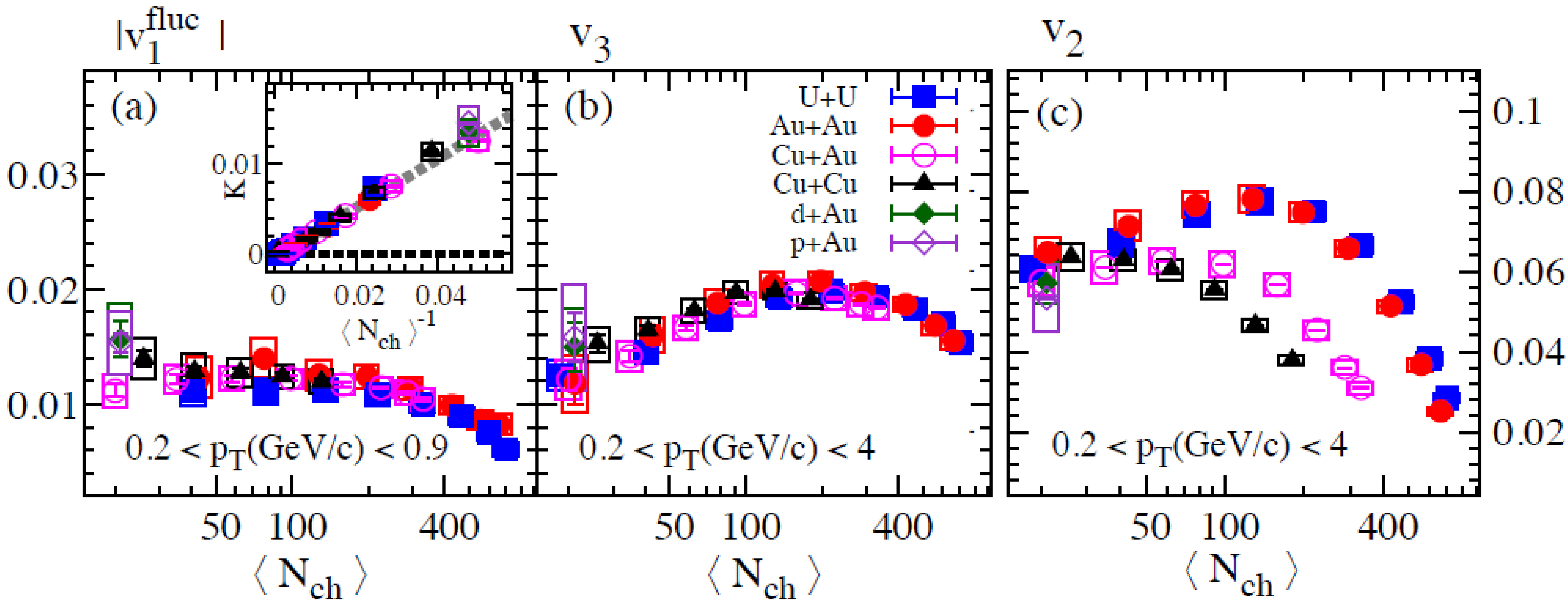
➢ **For a given n, $v_n(p_T)$ shows the predicted trends for all collision-systems.**

- ✓ v_1^{even} and v_3 *are system independent.*
- ✓ v_2 *is system dependent for sizeable $\langle N_{ch} \rangle$, but system-independent for small $\langle N_{ch} \rangle$.*
  - ✓ *The eccentricity-scaled v_2 is system independent*

Shape Response

Comparison of collision-systems
at ~ similar $\sqrt{s_{NN}}$ and $\langle N_{ch} \rangle$

STAR - arXiv:1901.08155



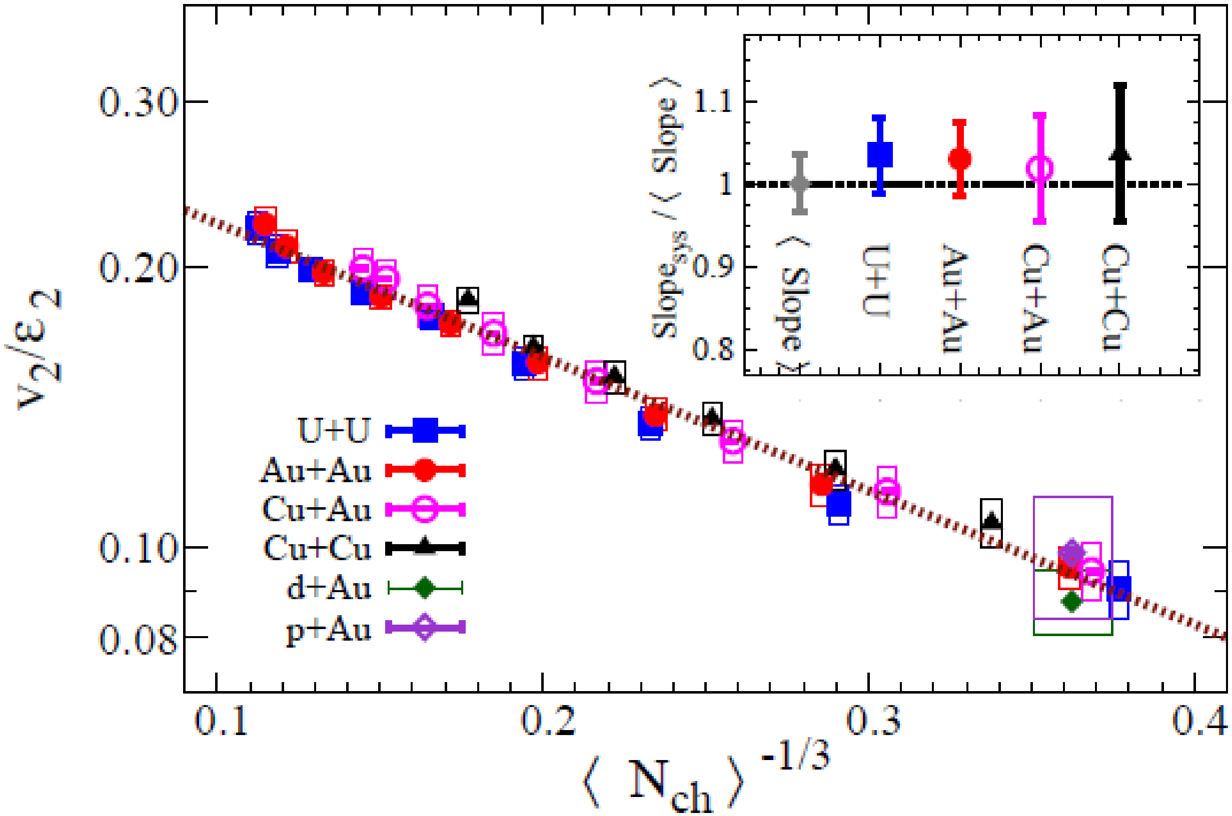
- ➢ ***For a given n, $v_n(N_{ch})$ show the expected trends for all systems.***
  - ✓ v_1^{even} and v_3 *are ~ system independent.*
  - ✓ v_2 *is system dependent for sizeable $\langle N_{ch} \rangle$, but system-independent for small $\langle N_{ch} \rangle$.*

Challenge to CGC-EFT models?

Acoustic Scaling – System size

arXiv:1901.08155

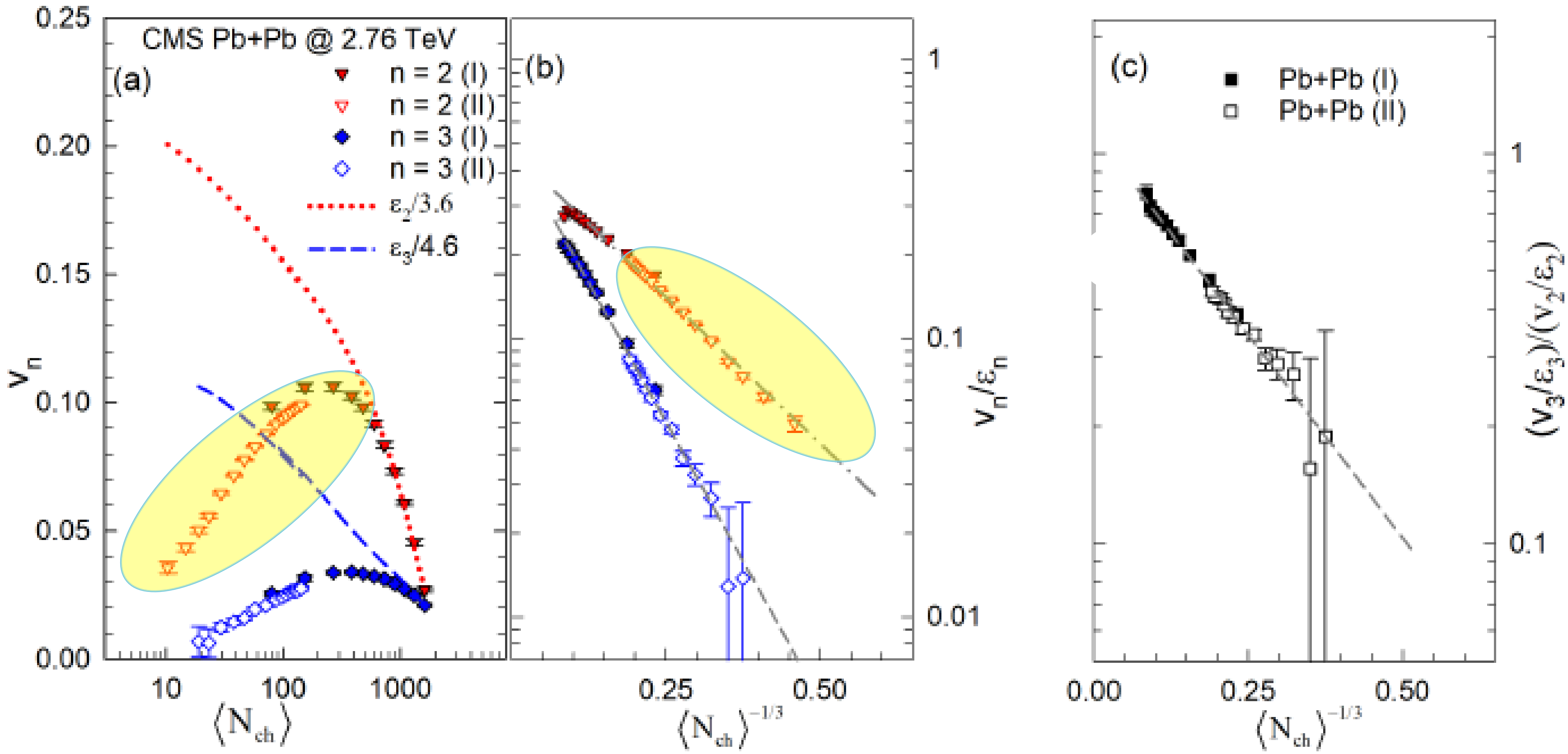
$\langle N_{ch} \rangle$ *dependence of* $\frac{v_2}{\varepsilon_2}$ *for several systems*



- ✓ **Characteristic 1/(RT) viscous damping validated**
- ✓ **Viscous damping very important for small dimensionless sizes.**
  - ✓ **Similar slopes imply similar $\frac{\eta}{s}$.**

Acoustic Scaling – System size

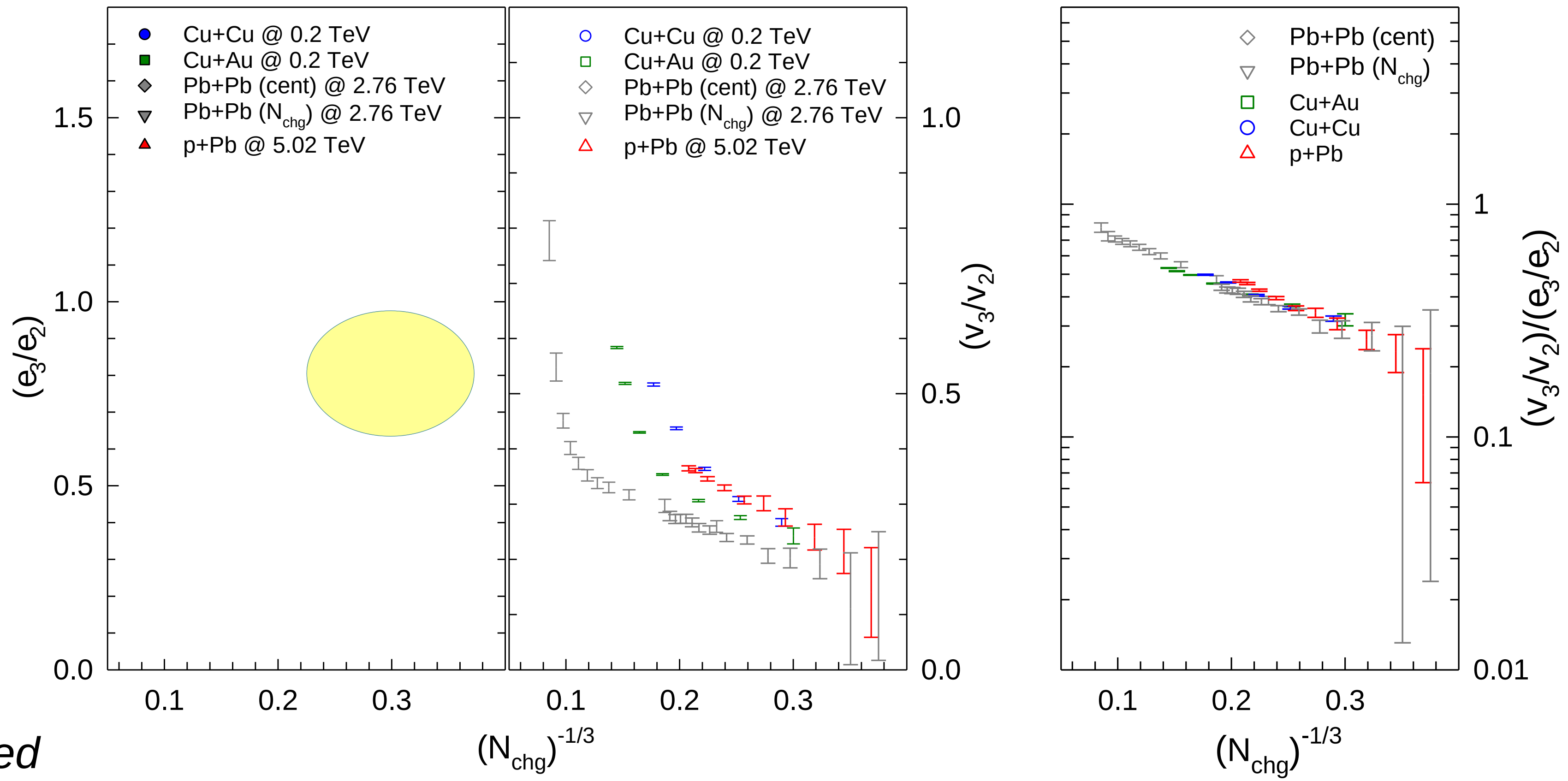
Phys. Rev. C **98**, 031901(R), 2018



- Eccentricity considerations <u>alone</u> not sufficient

- ✓ **Characteristic 1/(RT) viscous damping validated across dimensionless size**
- ✓ **Viscous damping supersedes the influence of eccentricity for "small" systems**
  - ✓ ***Important constraint for η/s & ζ/s***

Acoustic Scaling – System size

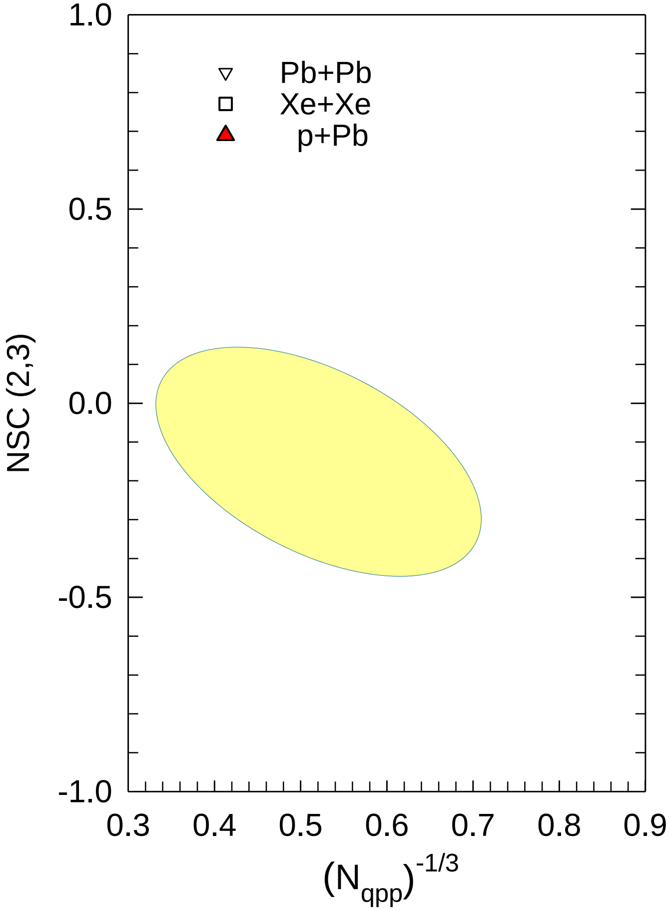


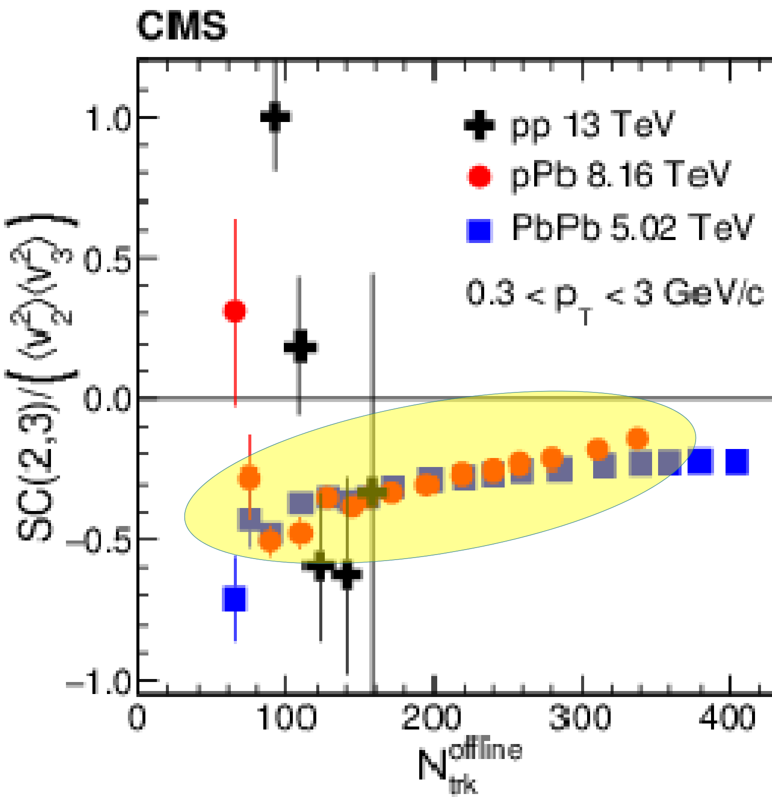
Submitted for Publication

- ✓ **Characteristic 1/(RT) viscous damping validated**
- ✓ **Viscous damping comparable for different collision-systems with similar dimensionless sizes**
  - ✓ ***Important constraint for η/s(T) & ζ/s(T)***

v_n correlations

- **Model discerning character of normalized symmetric cumulants**

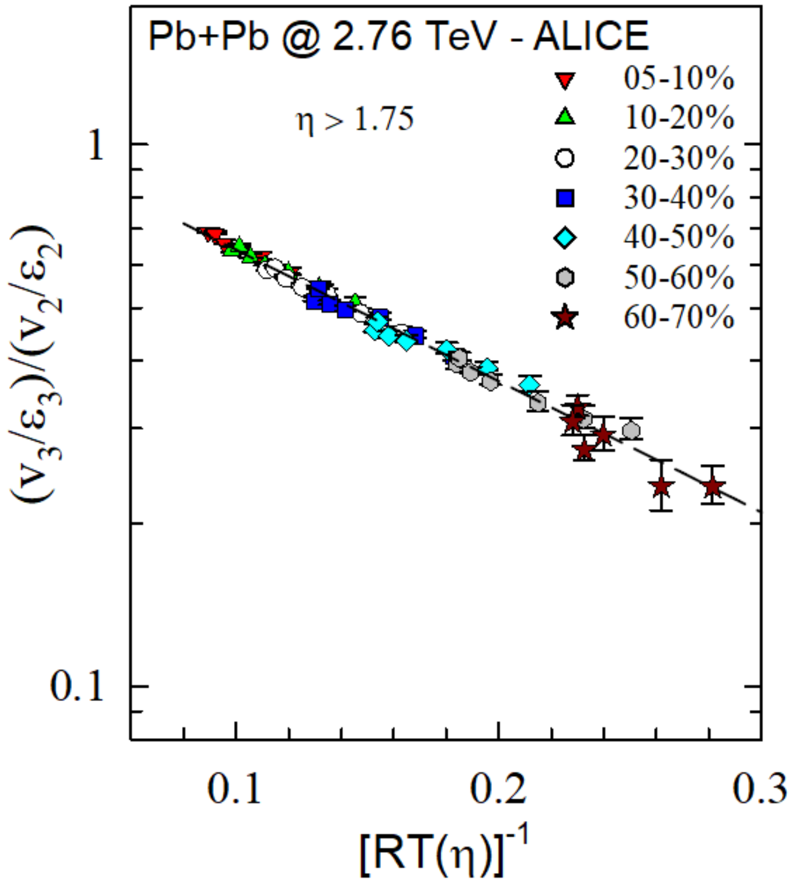


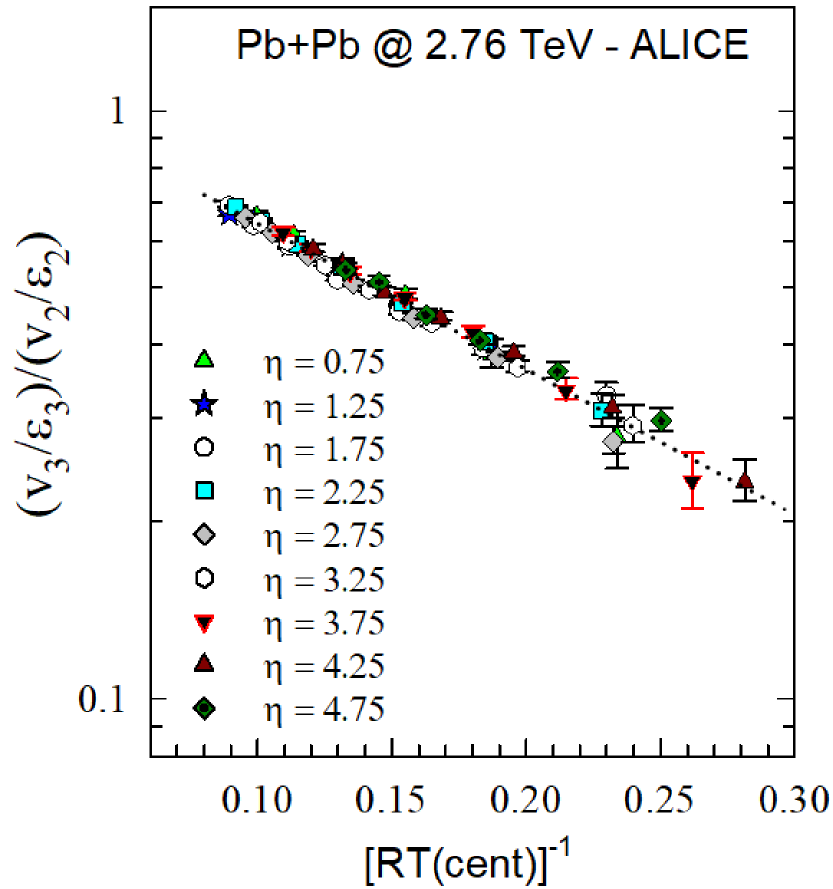


- ***Characteristic collision-system independent eccentricity anti-correlation***

This dependency poses a challenge for CGC-EFT models

Acoustic Scaling – eta dependence





- *The full data set scales*
  - ✓ *Implications for the temperature dependence of η/s (high T)!*

End