Longitudinal flow decorrelation by hydrodynamic fluctuations and event-shape engineering in Xe+Xe collisions

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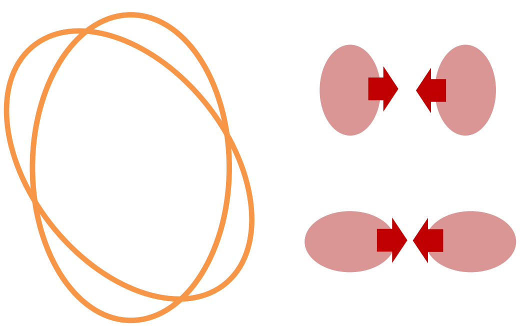
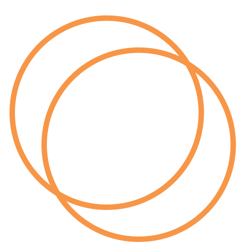
Question: An observable to experimentally distinguish *hydrodynamic fluctuations* (**HF**, dynamical thermal fluctuations) from *other types of fluctuations such as initial-state fluctuations*?

→ Any difference in their interplays with *non-trivial geometry*?



***Deformed* Xe+Xe**



***Spherical* Xe+Xe**

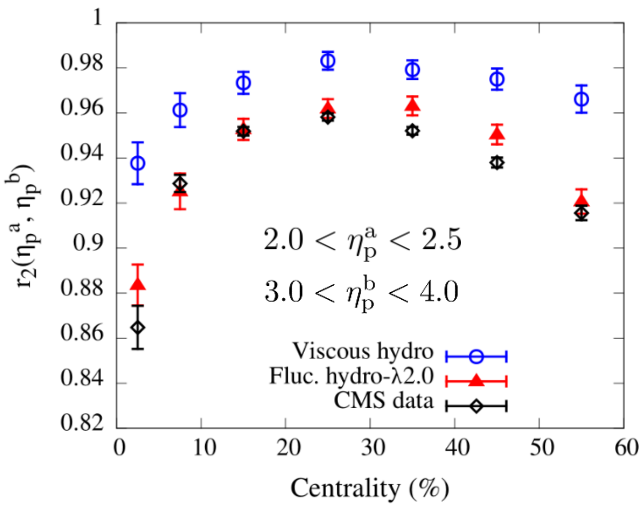
QUARK MATTER KRAKÓW 2022

Background

HF **are** ***thermal fluctuations of fluid fields***

[L. D. Landau and E. M. Lifshitz, *Fluid Mechanics* (1959)]

One of the observables that HF affects is *longitudinal flow decorrelation*

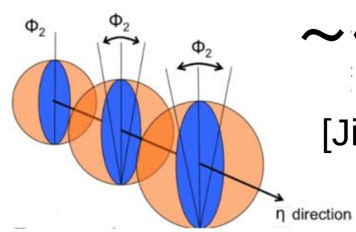


[A Sakai, KM, T Hirano, arxiv:2111.08963]

Factorization ratio "r_n"

$$r_n(\eta_p^a, \eta_p^b) = \frac{V_{n\Delta}(-\eta_p^a, \eta_p^b)}{V_{n\Delta}(\eta_p^a, \eta_p^b)}$$

$$\sim \langle \cos n[\Psi_n(-\eta_p) - \Psi_n(\eta_p)] \rangle < 1$$



[Jia and Huo, PRC**90** 034905 (2014)]

decorrelation of event-plane angle / flow magnitude fluctuations

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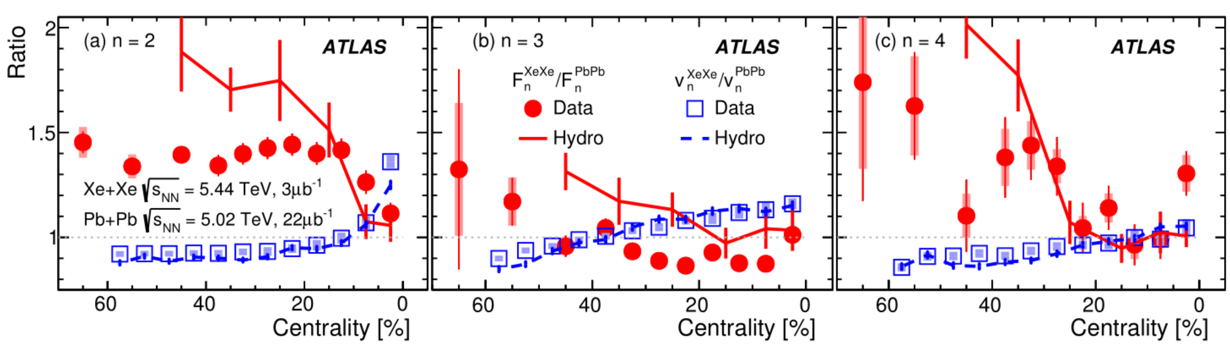
Recent measurements of decorrelation in Xe+Xe

[ATLAS Collaboration, Georges Aad, Phys. Rev. Lett. **126** (2021) 12, 122301]



$$r_n(\eta_p) = 1 - 2F_n\eta_p$$

Difference: XeXe vs PbPb

the effect of deformation?

Hydro model fail (without HF)

What a role *HF*s play here?

Model

Integrated dynamical model

1. **Initial condition**
   MC-Glauber/modified BGK
   (no initial longitudinal fluct.)
2. **rfh** -- **(3+1)-dim. Relativistic Fluctuating Hydrodynamics**
   EoS: lattice QCD & HRG, $\eta/s = 1/4\pi$
3. **Particlization** at T_{sw} = 155 MeV
   Cooper-Frye formula: $f_0 + \delta f$
4. **JAM** (only decays at the moment)

Initial condition: Xe+Xe 5.44 TeV

Deformed Xe		**"Spherical Xe"**
^{129}Xe β_2 = 0.162, β_4 = -0.003.	VS	^{129}Xe β_2 = 0.0, β_4 = 0.0.

Woods-Saxon with deformation

$$\rho = \frac{\rho_0}{1+\exp\left(\frac{r-R(\theta)}{a}\right)}.$$

R_0 = 5.42,
a = 0.55,
ρ_0 = 0.166

G. Giacalone, et al, Phys. Rev. C 97, 034904 (2018); P. Mller, et al, Atom. Data Nucl. Data Tabl. 109-110, 1 (2016).

HF are introduced in hydro eq. as *noise terms* ***ξ(x)***

Constitutive eq for shear stress

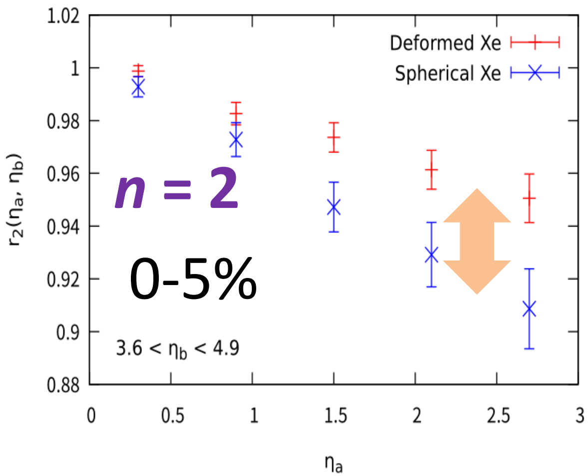
$$\tau_\pi \Delta^{\mu\nu}{}_{\alpha\beta} u^\lambda \partial_{;\lambda} \pi^{\alpha\beta} + \pi^{\mu\nu}\left(1+\frac{4}{3}\tau_\pi \partial_{;\lambda} u^\lambda\right) = 2\eta \Delta^{\mu\nu}{}_{\alpha\beta} \partial^{;\alpha} u^\beta + \xi^{\mu\nu}$$

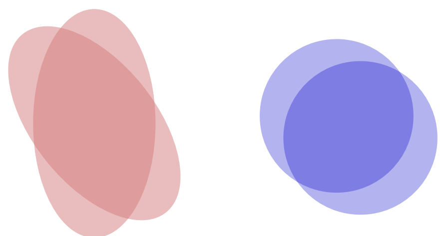
HF = Noise term

Magnitude determined by
fluctuation-dissipation relation

$$\langle \xi^{\mu\nu}(x) \xi^{\alpha\beta}(x') \rangle = 4T\eta \Delta^{\mu\nu\alpha\beta} \delta^{(4)}(x-x')$$

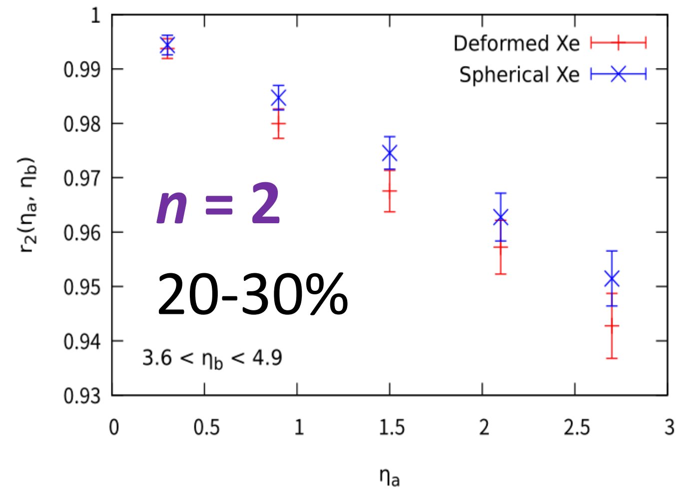
Result: $r_n(\eta_p^a,\eta_p^b)$ for deformed vs spherical Xe





less decorrelate ← stronger geometry

more decorrelate



Decorrelation by HF is affected by the deformation in central collisions

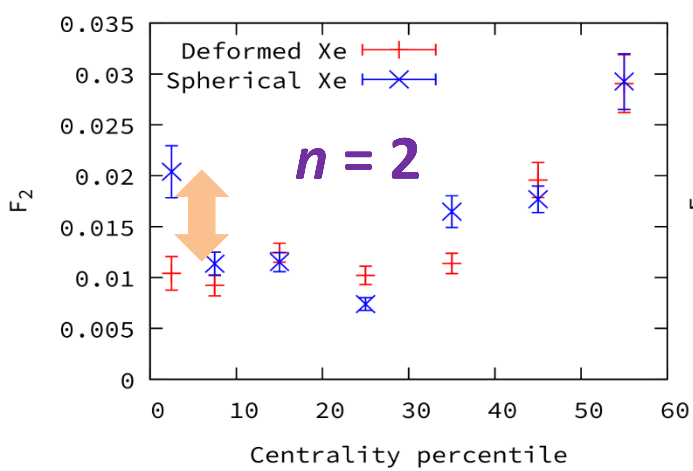
No clear difference in non-central collisions

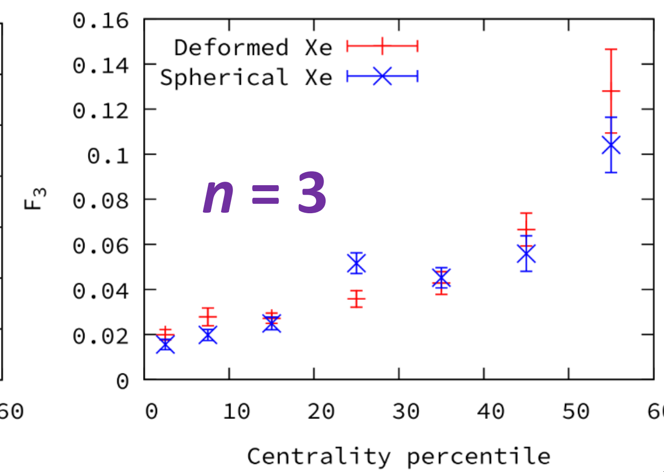
Slope parameter F_n: $r_n(\eta_a) = 1 - 2 F_n \eta_a$ … magnitude of decorrelation

Centrality dependence

Elliptic-flow decorr. in central collision is suppressed

Higher-order (n=4, 5) do not receive clear effects

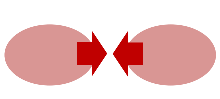




Result: Event selection by q_2

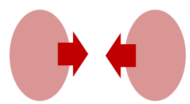
Effect of nuclei orientation in the central collisions?

tip-tip collisions



smaller eccentricity
larger multiplicity

body-body collisions



larger eccentricity
smaller multiplicity

Q. How is the decorrelation changed by the orientation?

Event-shape engineering

[Schukraft, Timmins, Voloshin, Phys. Lett. B719, 394 (2013)]

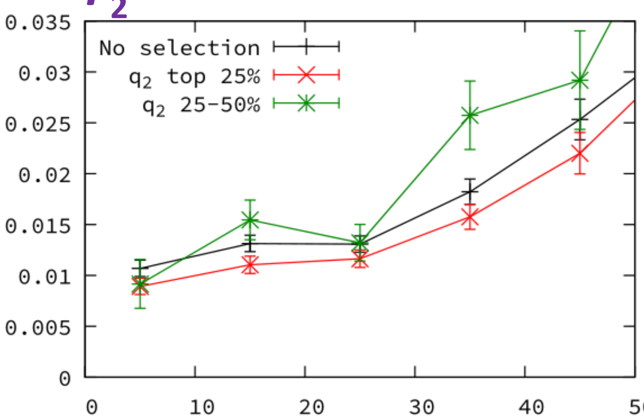
Event selection by "the shape"

$$q_2 = \frac{1}{\sqrt{M}}|Q_2|, \quad Q_n = \sum_{i=1}^{M} e^{in\phi_i}$$

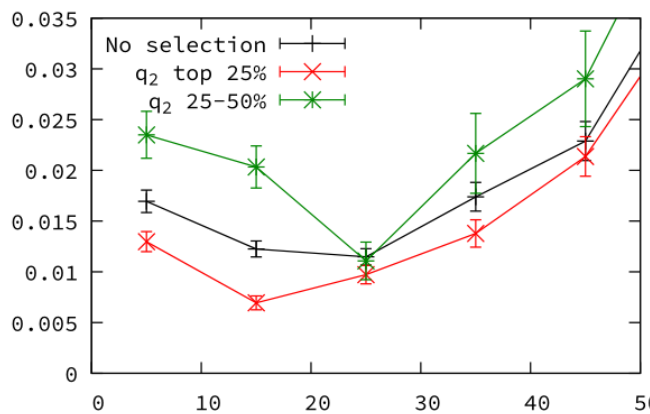
$1.7 < |\eta_p| < 3.7$

→ classify events by the magnitude of q_2

***F*$_2$**



Deformed Xe+Xe



Spherical Xe+Xe

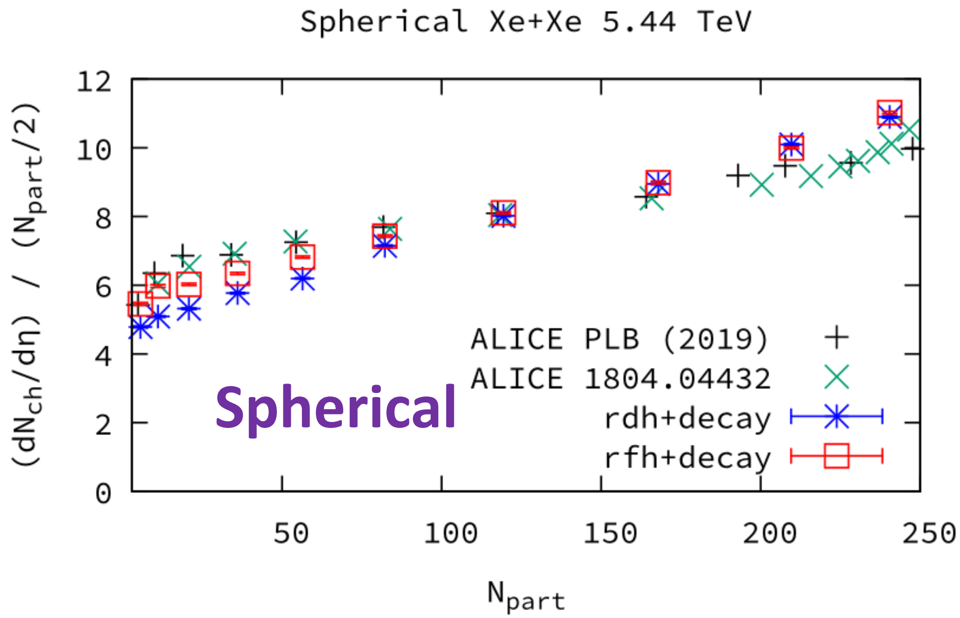
q_2 dependence becomes weaker by deformation

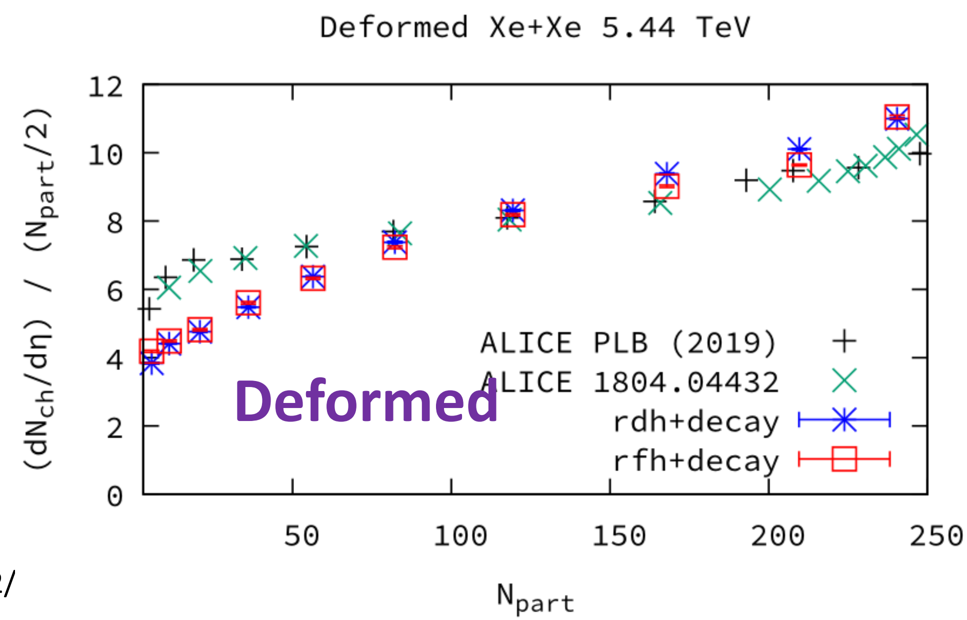
Needs selection in ultracentral collisions (i.e., more statistics)

Outlook Cascade effects, ultracentral, more statistics, comparison w/ Pb+Pb and data

BACKUP

Binary-collision scaling



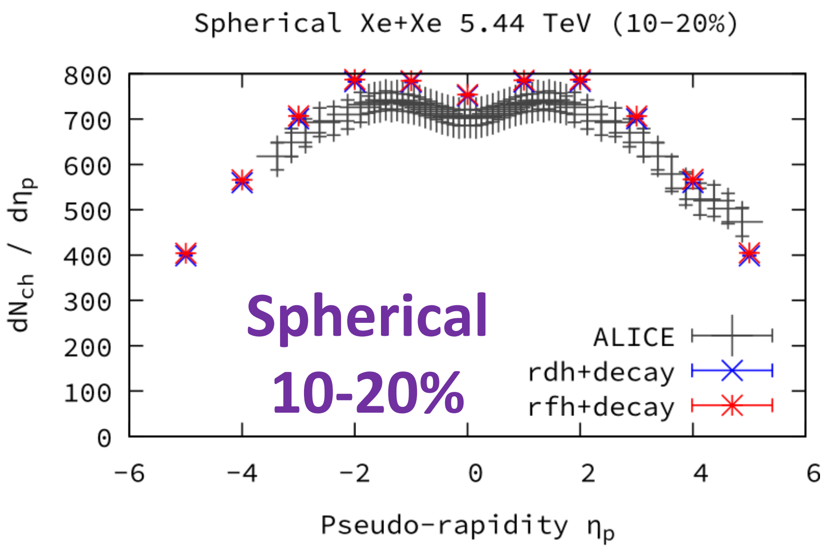


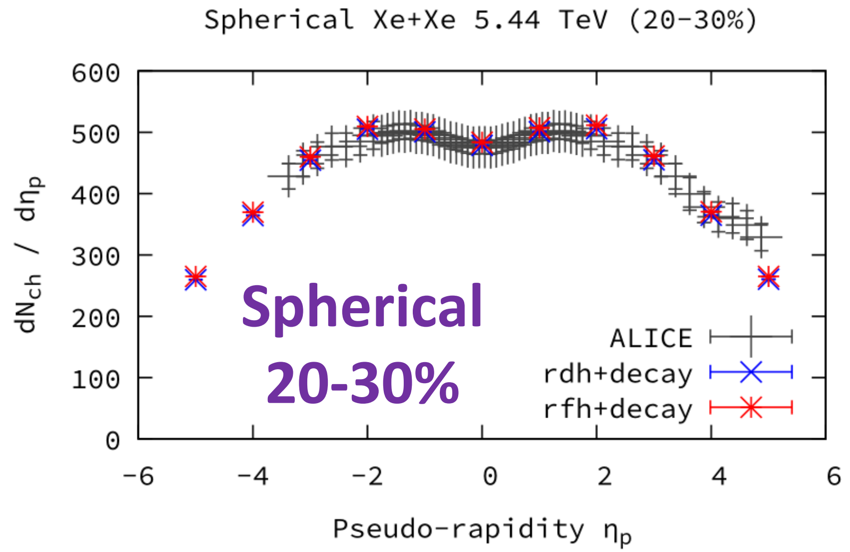
rdh: no fluctuations,
rfh: with hydro fluctuations

Glauber parameters
Normalization $s_0 / (N_{part}/2)'$ = 66, 70
Hard fraction $\delta = 0.16$

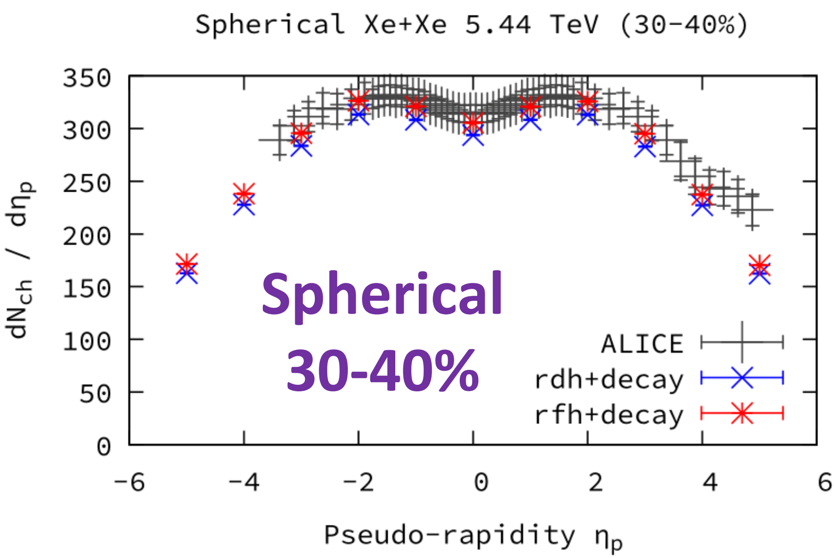
Modified BGK f_{pp} parameters
$\sigma_\eta = 3.6$
$\Delta\sigma = 1.6$

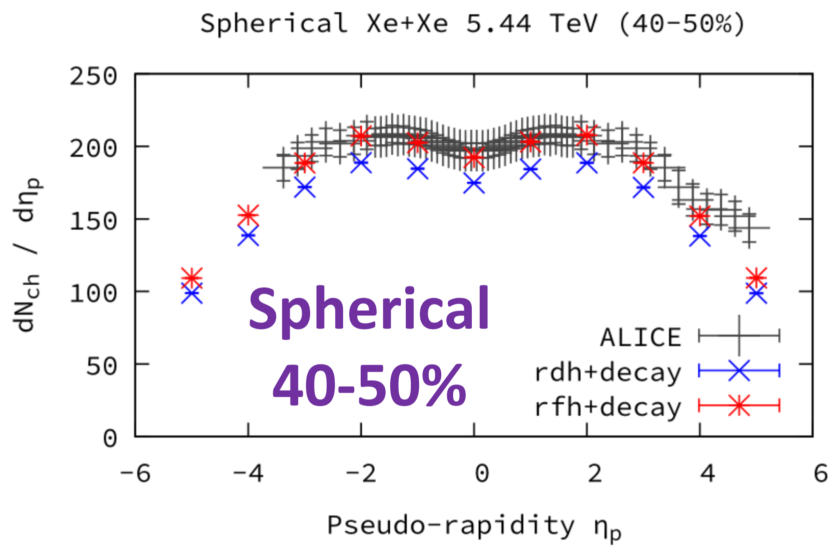
Charged-particle multiplicity $dN/d\eta_p$



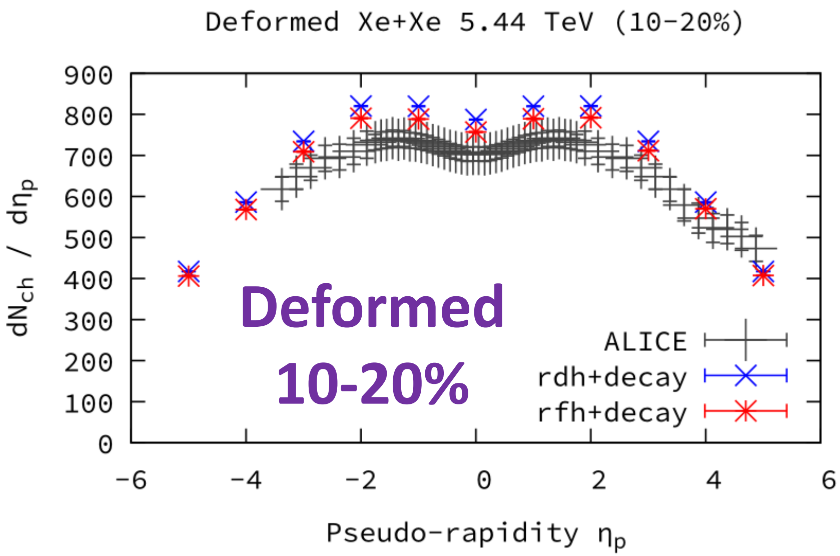


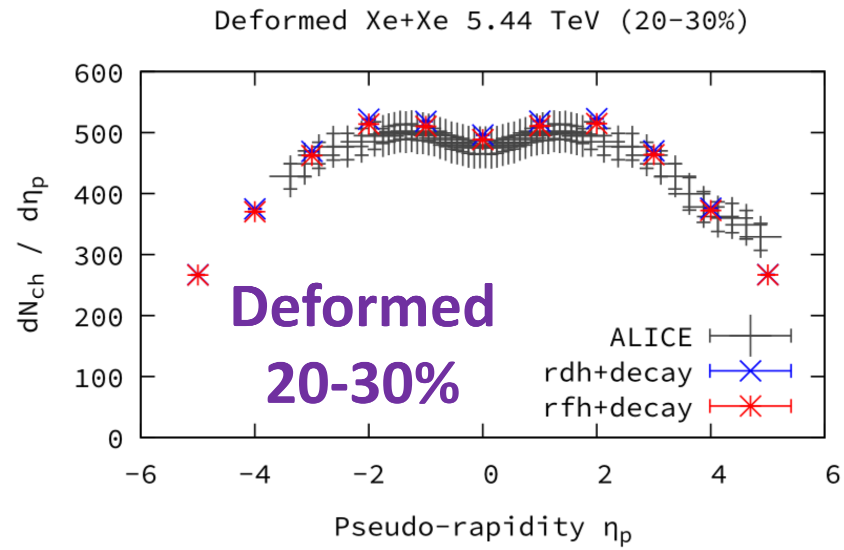
rdh: no fluctuations, rfh: with hydro fluctuations





Charged-particle multiplicity $dN/d\eta_p$





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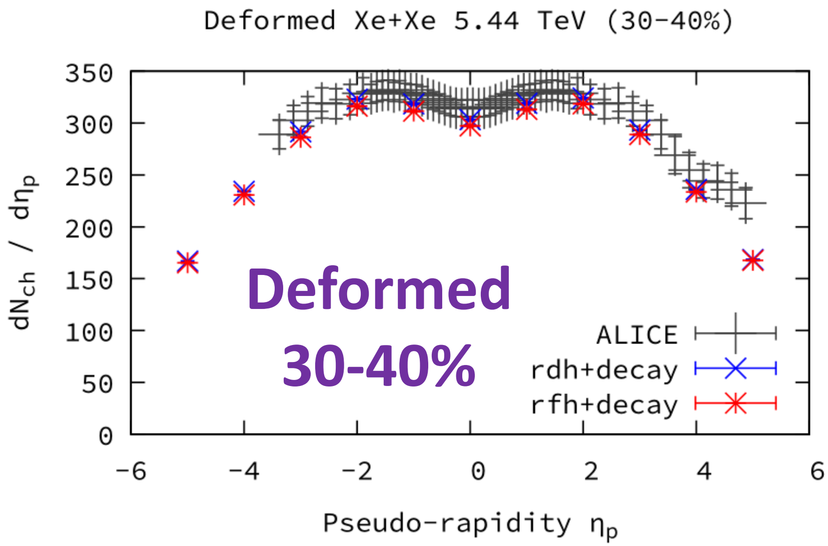
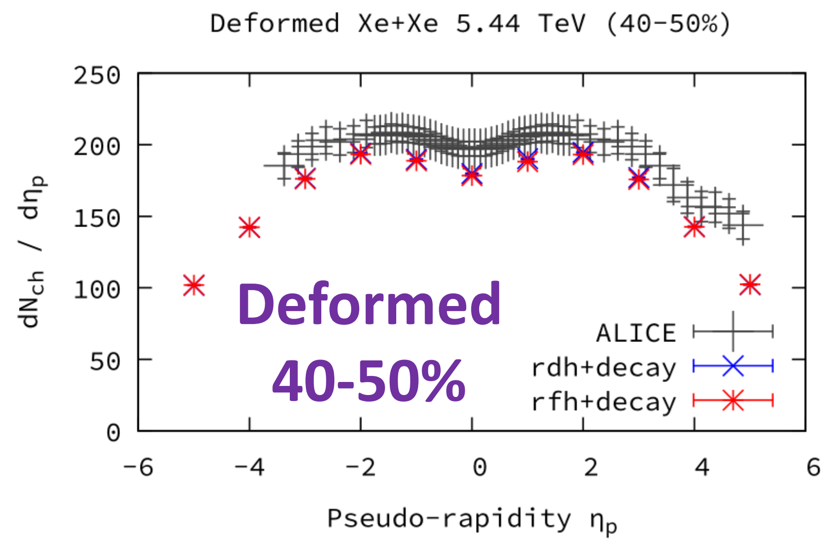
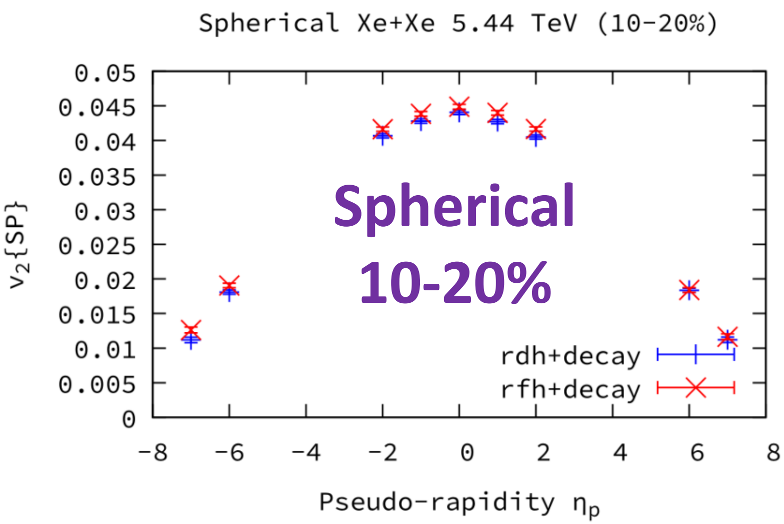
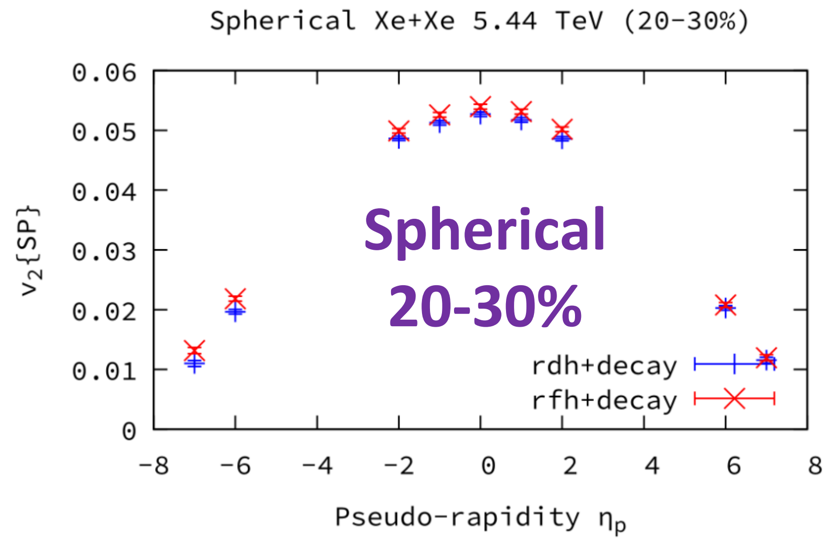


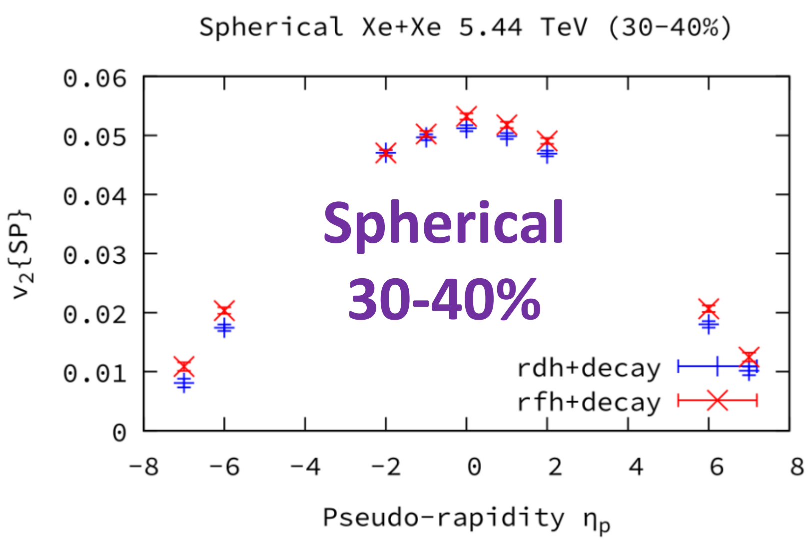


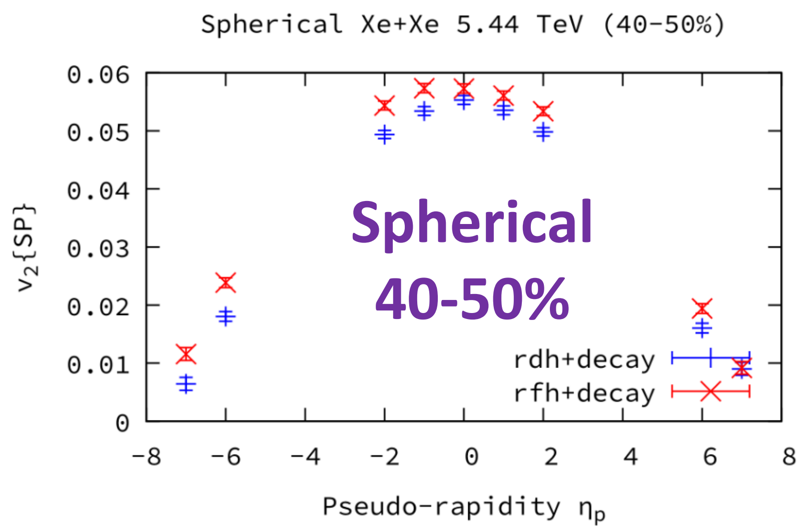
Elliptic flow v_2\{SP\} vs η_p (ref $2.8 < |\eta_p| < 5.1$)



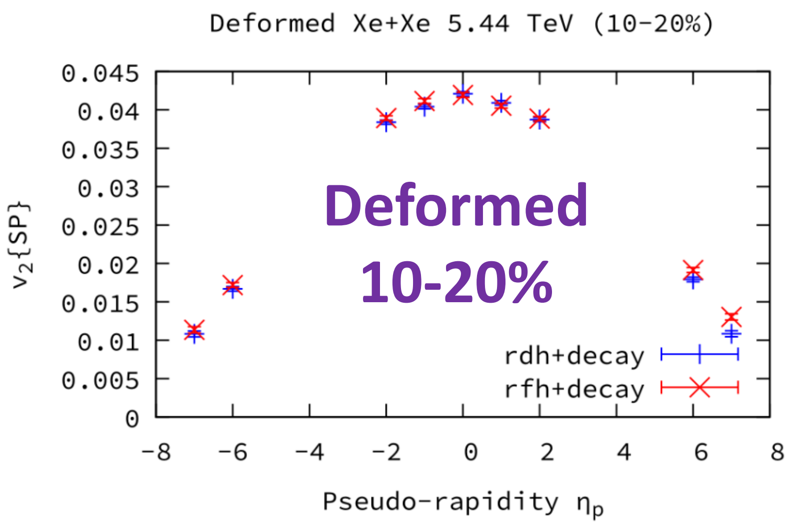


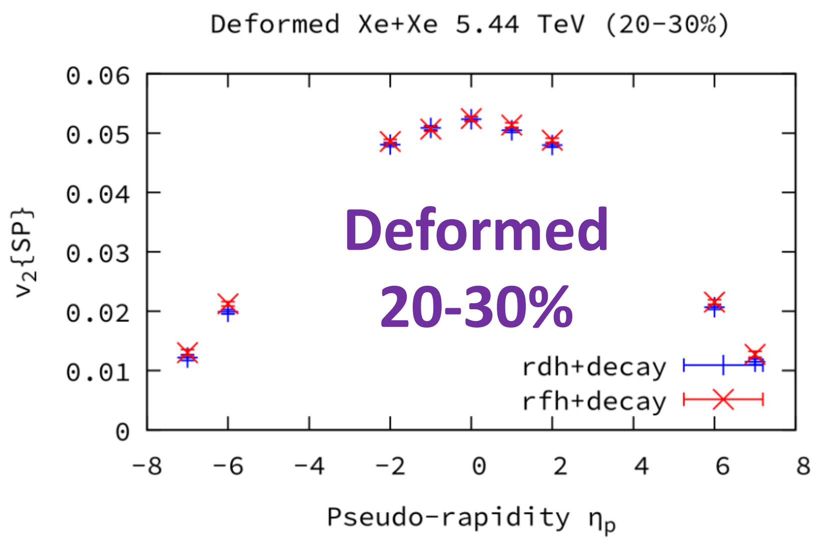
rdh: no fluctuations, rfh: with hydro fluctuations





Elliptic flow $v_2\{SP\}$ vs η_p (ref $2.8 < |\eta_p| < 5.1$)





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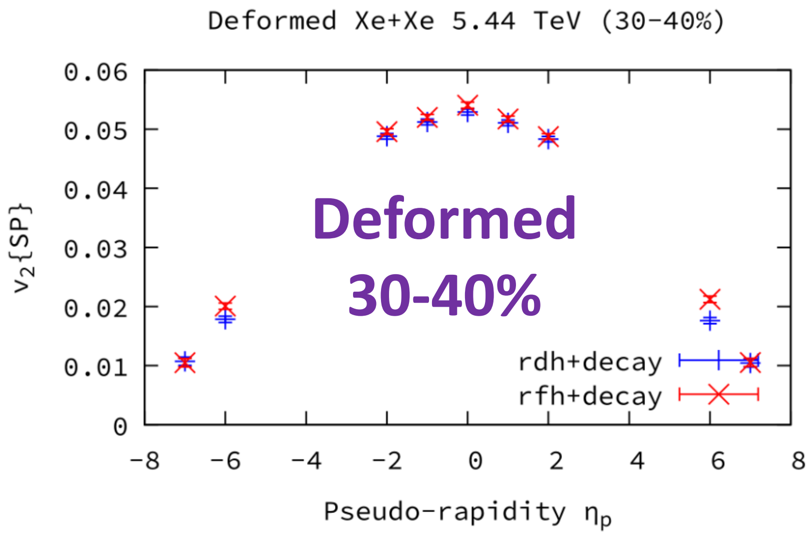
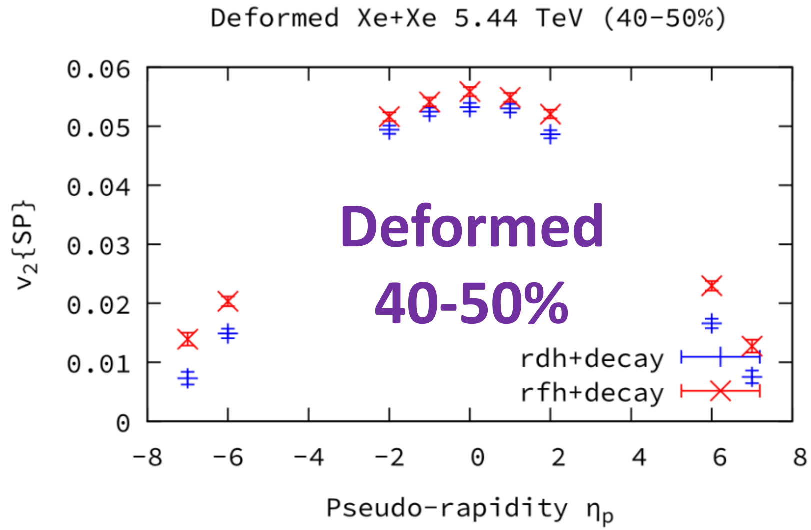
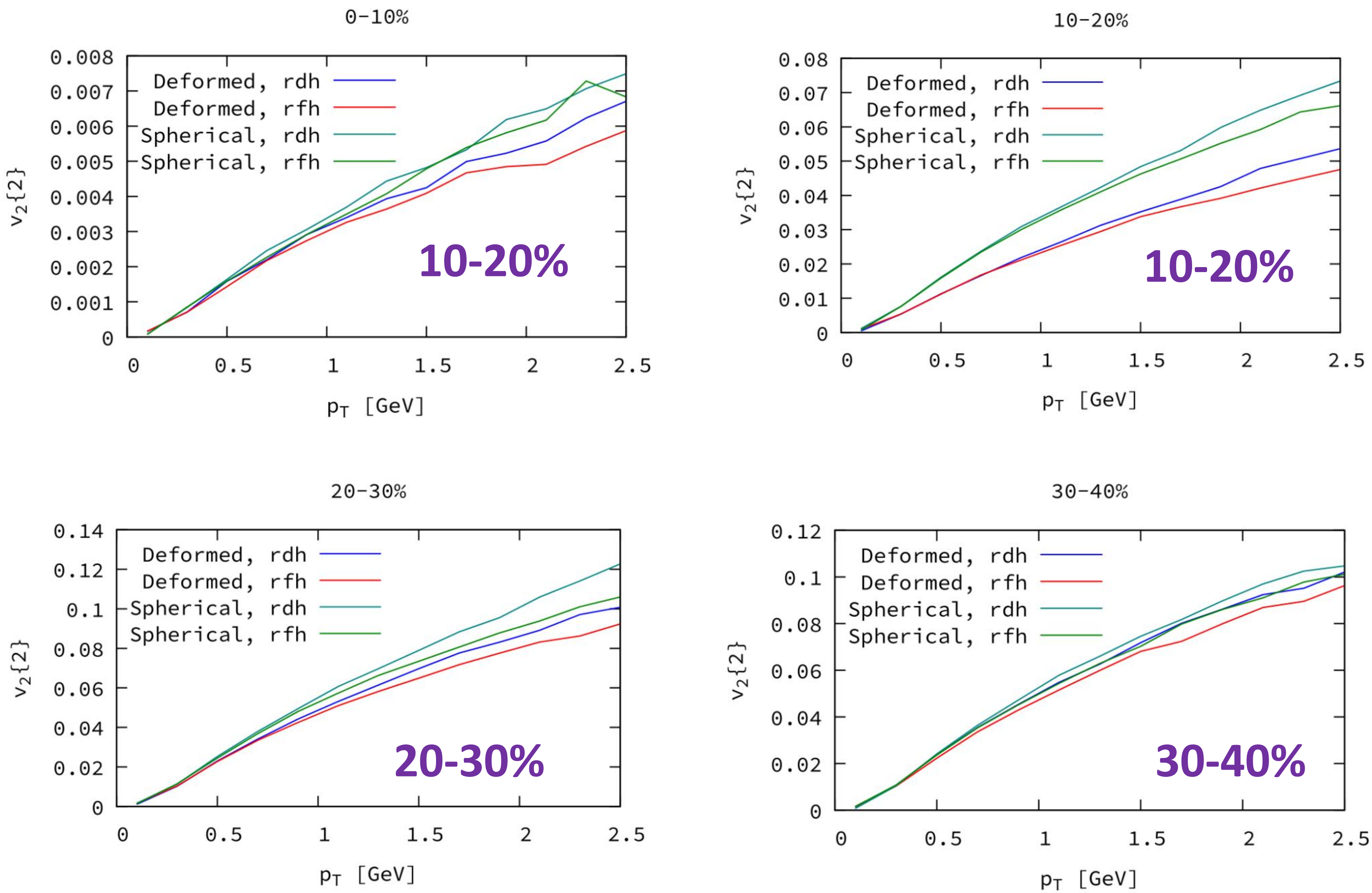
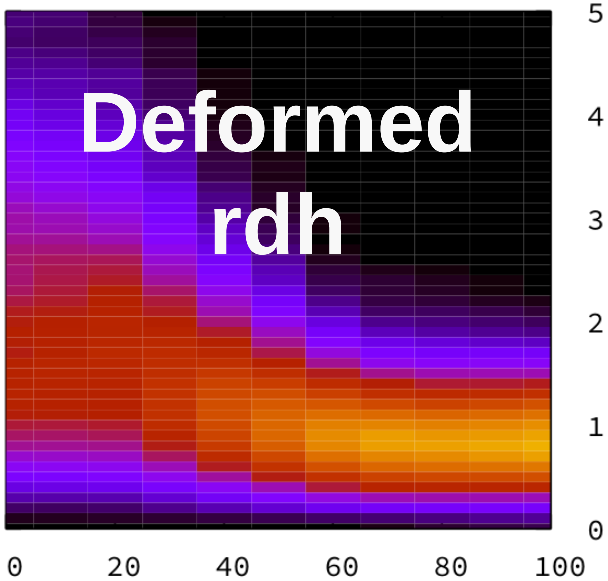


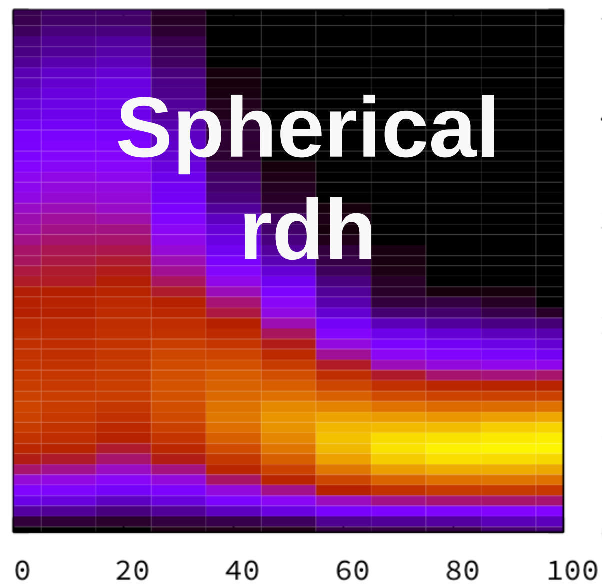


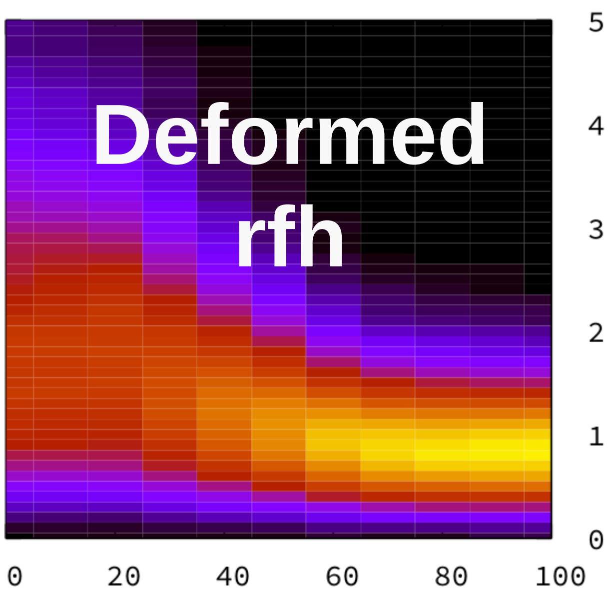
Differential elliptic flow $v_2\{2\}$

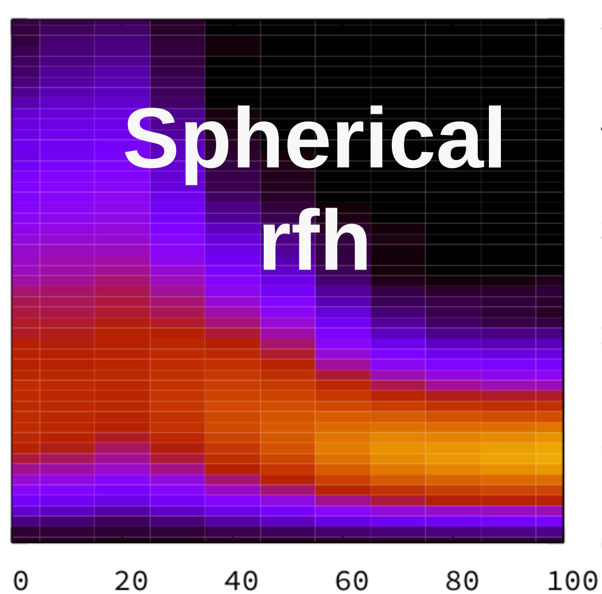


q_2 distribution ($1.7 < |\eta_p| < 3.7$)

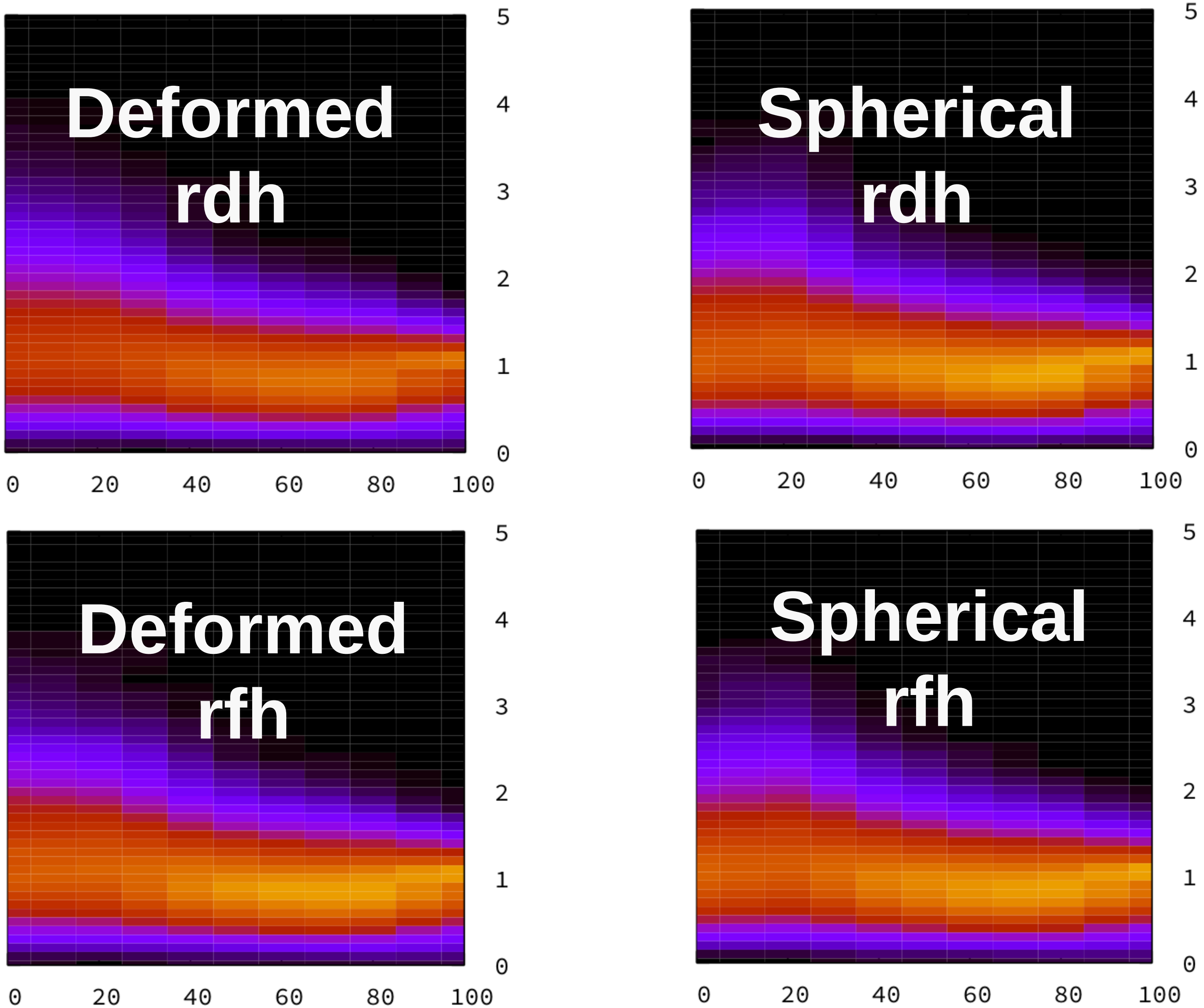






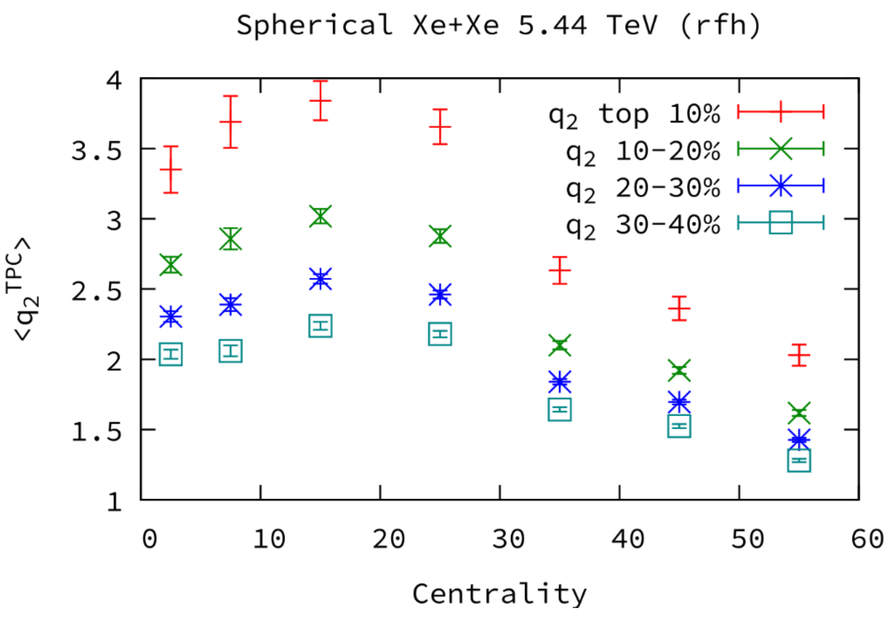


q_2^{TPC} distribution ($|\eta_p| < 0.4$)

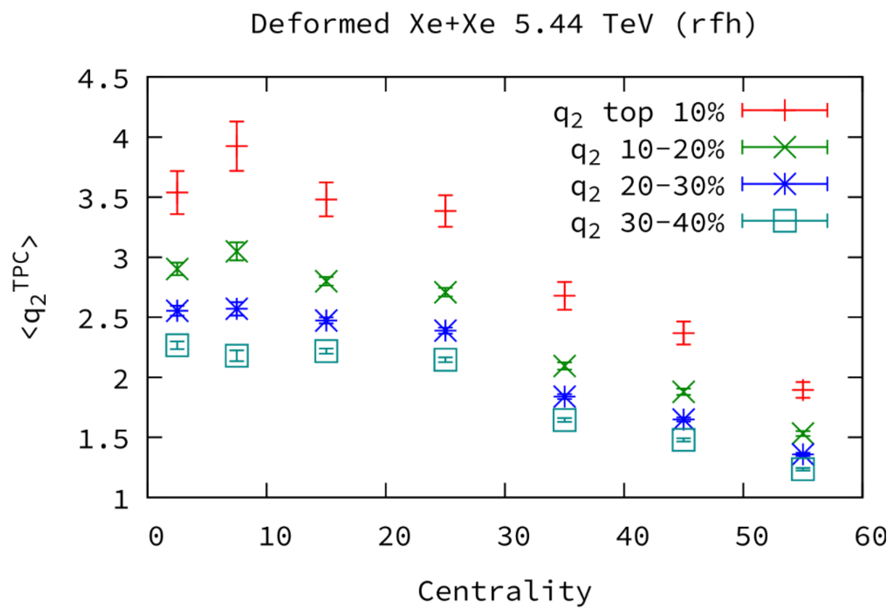


$\langle q_2^{TPC} \rangle$ in each q_2 class

Spherical

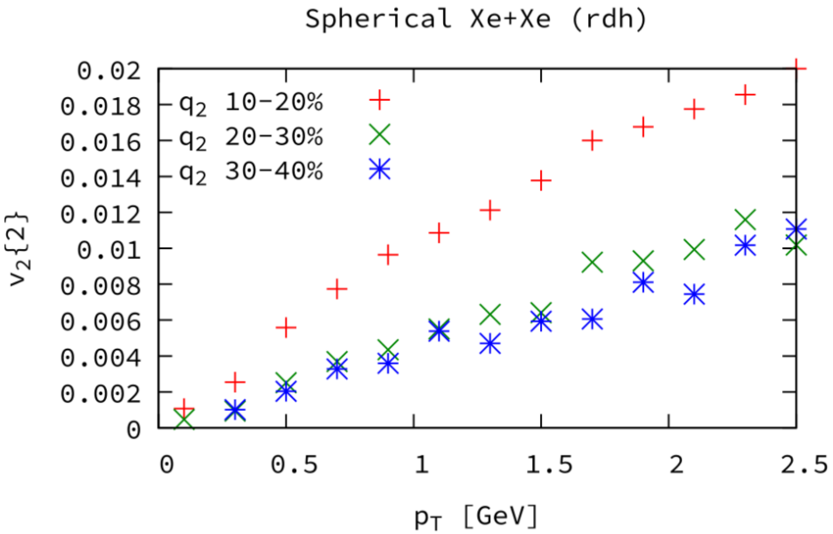


Deformed

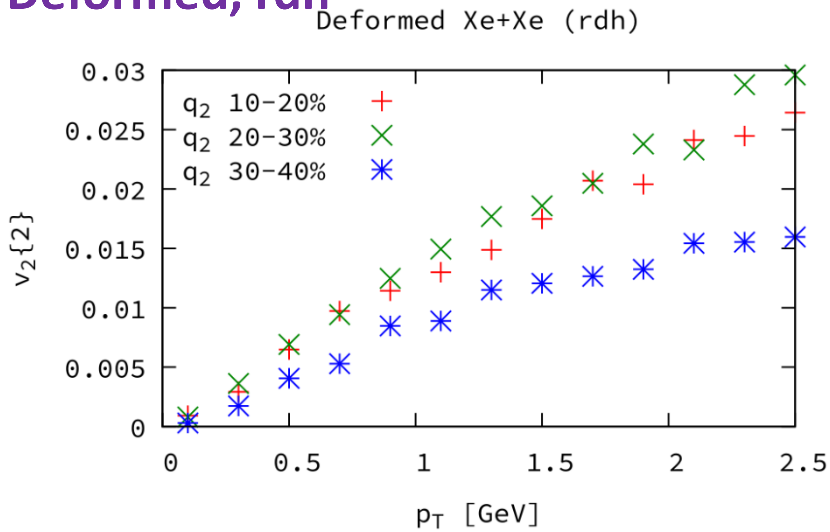


ESE $v_2\{2\}$ 0-10%

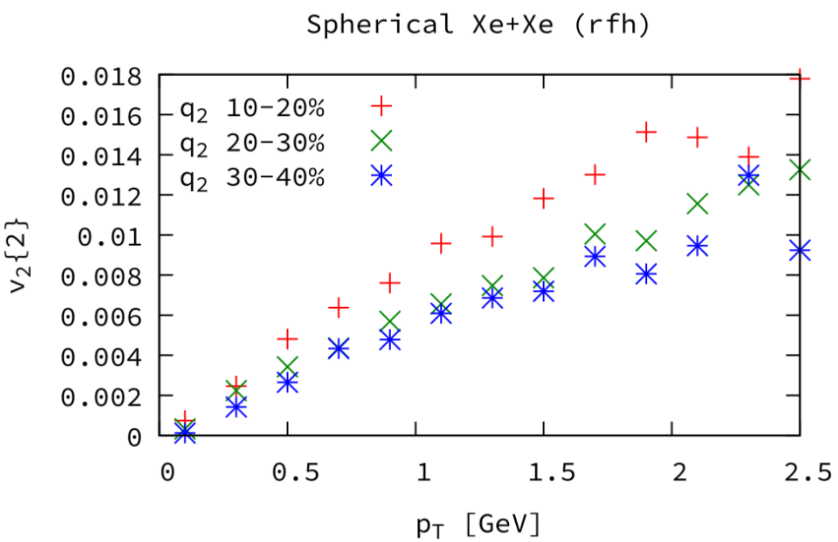
Spherical, rdh



Deformed, rdh



Spherical, rfh



Deformed, rfh